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Proceedings of the American Society of Civil Engineers

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SECTOR ANALYSIS FOR CONCRETE PAVEMENT LOAD STRESSES

Bengt F. Friberg,[1] M. ASCE
(Proc. Paper 1153)

SYNOPSIS

This paper is an outline of Sector Analysis, an approximation method of elastic analysis for slabs subjected to tire-imprint loads and resting on yielding subgrades. The method is used for a wide range of loaded-area dimensions, and for slabs of limited dimensions, such as highway and airport pavements.

The principles and procedures are described, and Sector Analysis is applied to stress and deflection determination in slabs of conventional highway dimensions subjected to single-wheel loadings for which comparative test observations are available. Stresses computed by Sector Analysis are in line with test observations. Application to common highway axle loadings is illustrated and compared with test road observations.

Sector Analysis is shown to provide a simple and sufficiently accurate design tool for the complex load and stress conditions of limited-dimension pavement slabs.

INTRODUCTION

Scope

The term "Sector Analysis" denotes the graphical-arithmetical approximate method outlined in this paper for analysis of flexural stresses and deflections of elastic plates resting on yielding subgrades or bases, when subjected to wheel imprint loads of limited outline. Sector Analysis is intended particularly for investigation of load stresses and deflections in conventional concrete pavements for highways and airports under wheel and axle loadings.

Sector Analysis is applied especially to consideration of stresses in the longitudinal and transverse directions in slabs of limited width such as

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pavement lanes, to appraisal of the influence of non-circular loaded areas on stresses, particularly as related to dual-tire wheel imprints, and to stress and deflection determination for the two wheel imprints of axle loads and tandem axles. In this presentation only "normal" subgrades, with reaction proportionate to deflection, and single wheel and axle loadings have been included.

Historical Notes

The reader is referred to a paper by Kelley[1] for comprehensive information on the development of pavement load stress formulas. All past investigators have recognized the representative wheel load positions of corner-, interior-, and edge-loading for stress investigations. Those principal load positions are used in Sector Analysis as well.

The "corner formula," Fig. 1, suggested by Goldbeck[2] in 1919 has been applied extensively to pavement design, although limited to corner stress and intended only as an approximation. Subgrade pressure, and tire imprint size which for modern traffic may extend a substantial distance from the corner, were neglected, resulting in too high values of stress; the flexure was assumed uniformly distributed across plane sections at 45-degree angle with the edges, a liberal assumption resulting in too low values for maximum stress. These approximations in part counterbalance each other, especially for small wheel imprints. The corner formula is not usable for modern traffic loads.

The Westergaard[3] equations, Fig. 2, published in 1925, were derived by rigorous mathematical concepts for loaded plates on elastic foundations, with the wheel imprint represented by circular, and for edge loading halfcircular, areas, and with infinite extension of the plate from the origin. Neither of these assumptions applies for normal design wheel loads and limited-dimension pavement slabs. Further departures from assumptions result for axle loading.

Teller and Sutherland[4] have made a comprehensive experimental investigation of load stresses in concrete pavement slabs, combined with appraisal of the Westergaard equations for single loads. As a result, empirical modifications of the Westergaard equations were proposed, as shown in Fig. 2, to fit observed maximum load-stress changes in warped slabs. The research provides a wealth of experimental data, for comparisons with theories, on slabs loaded with single wheel loads.

M. G. Spangler,[5] investigating corner load stresses, has called attention to the non-linear orientation of structural corner breaks, approaching a circular arc having the corner as center, and shows a derivation of stress considering cylindrical critical sections for a rectangular corner loaded some distance from the corner.

Following up these suggestions of Spangler, Sector Analysis has been formulated as a generalized simplification of stress derivations for cylindrical sections. The theory has been extended to cover interior- and edge- as well as corner-loading, and to consideration of load stress conditions in relatively narrow pavement lanes for wheel and axle-loadings, as shown in Fig. 3.

The aim of Sector Analysis is to reproduce the approximately corrent bending of the slab under load in the simplest possible terms, so that consideration can be given to dimensional limitations and anomalies in visual

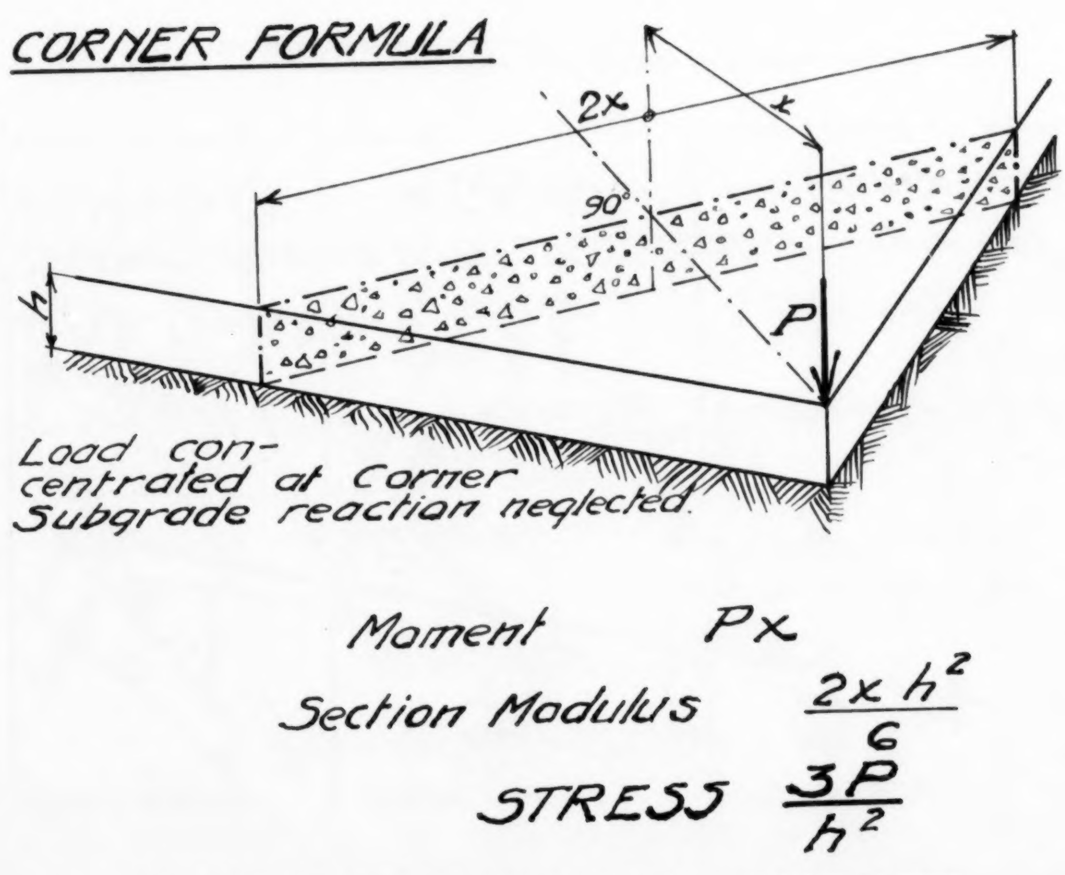
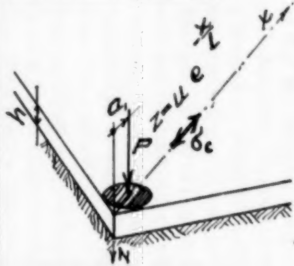
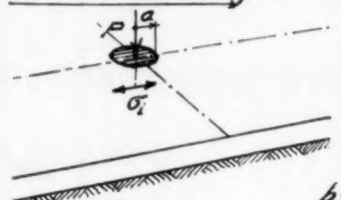
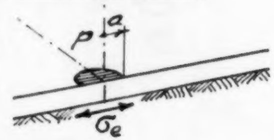


Fig. 1 Cantilever beam concept for pavement load concentrated at the corner

Corner Loading	Interior Loading	Edge Loading
		
	$l = \sqrt[4]{\frac{Eh^3}{12(1-\mu^2)k}}$	$b = a$, for $a > 1.724h$; if less: $b = \sqrt{1.6a^2 + h^2} - .675h$.

STRESSES

$\sigma_c = \frac{3P}{h^2}\left\{1 - \left(\frac{a_1}{l}\right)^{0.6}\right\}$	$\sigma_i = .275(1+\mu)\frac{P}{h^2}\log_{10}\left(\frac{Eh^3}{kb^4}\right)$	$\sigma_e = .529(1+.54\mu)\frac{P}{h^2}\left\{\log_{10}\left(\frac{Eh^3}{kb^4}\right) - .71\right\}$

DEFLECTIONS

$z = \frac{P}{kl^2}\left(1.1e^{-\frac{x}{l}} - \frac{a_1}{l}.88e^{-\frac{2x}{l}}\right)$	$z_i \sim \frac{P}{8kl^2}$	$z_e \sim \frac{1}{\sqrt{6}}(1+.4\mu)\frac{P}{kl^2}$

EQUATIONS MODIFIED TO FIT TEST RESULTS To year 1943.

$\sigma_c = \frac{3P}{h^2}\left\{1 - \left(\frac{a_1}{l}\right)^{1.2}\right\}$ (Corner warped up)	$\sigma_i = .316\frac{P}{h^2}\left\{\log_{10}\left(\frac{Eh^3}{kb^4}\right) - .9\right\}$ $\mu = .15$	$\sigma_e = .572\frac{P}{h^2}\left\{\log_{10}\left(\frac{Eh^3}{k \cdot b^4}\right) + \log_{10} b - 1.08\right\}$ (Edge warped up), $\mu = .15$

Fig. 2 Westergaard pavement stress equations, with modifications suggested by stress observations on warped slabs.

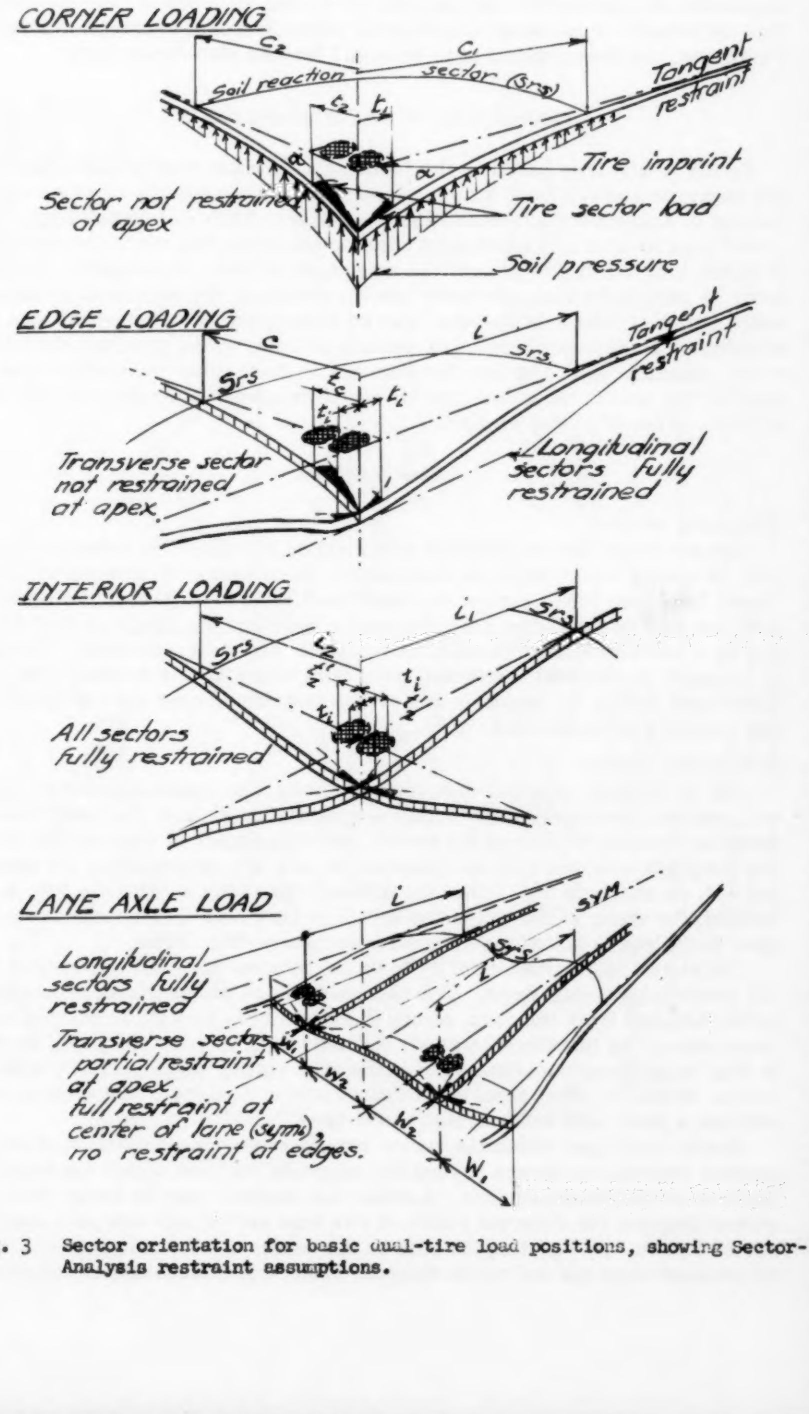


Fig. 3 Sector orientation for basic dual-tire load positions, showing Sector-Analysis restraint assumptions.

procedural steps. Load stresses and slab deflections due to load may thus be estimated and adjusted to limiting slab conditions as a better representation than the results of mathematical formuli which, however correct for idealized conditions, are less applicable to the usual limited slab dimensions.

PRINCIPLES OF SECTOR ANALYSIS

Sector Analysis is based on the finding that a wheel load is distributed to the subgrade radially over a fan-shaped area, the dimensions of which are related to subgrade characteristics, to pavement depth and dimensions, to the wheel imprint area and location of other wheel loads, but not to the magnitude of wheel load which affects only the magnitude of deflections and not the distance to zero deflection. It shows how the principal dimensions of the fan-shaped area of subgrade reaction may be determined, how the wheel load is distributed on different elemental sectors oriented in the principal directions of the pavement slab, and how the stresses in these principal sectors are related to the size of the wheel imprint and to dimensional limitations and restraints of the principal sectors.

General Outline

Elemental Sectors

The pavement slab is analyzed as a number of contiguous individual sectors extending outwardly from each wheel. Each sector is considered to be loaded by a distributed part of the wheel load at an even intensity of pressure over the part of the sector near the apex covered by the single or dual tire, and by a corresponding and equal soil reaction from the underside. The apex is assumed at the most convenient point with respect to each wheel load, as illustrated in Fig. 3. Moments are evenly distributed over the circumpherential arcs of the elemental sectors.

Sector Dimensions

For an initially assumed distribution of subgrade reaction under the sector, and for tire imprints extending varying distances from the apex measured as fractional parts of the sector, the components of moment due to load and subgrade reaction may be computed for any arc section from the apex to the end, as shown in Fig. 4, and for different tire imprint sizes in Fig. 5. As defined, the shear at the end of the sector is zero, and the distance from the apex to the end is called the subgrade reaction sector radius.

The stress is obtained directly from the moment for each arc section for any specific pavement depth. The section width or arc is direct proportionate to the distance from the apex, points of equal stress as well as point of maximum stress can therefore be easily located on the moment diagram, as shown in Fig. 4, by lines from the origin at the apex cutting or tangent to the moment curve. It will be seen, also, that flexural stress directly at the apex occurs only for a point load concentrated at the apex.

Stress conditions within the sector permit some prognostication of the gradual decrease in stress beyond the subgrade reaction sector radius in slabs of unlimited dimensions. A deflection diagram may be drawn from each stress diagram for different ratios of tire load sector and subgrade reaction sector radius. By equating the load on the sector and the subgrade reaction as obtained from the deflection diagram numerical dimensions of subgrade

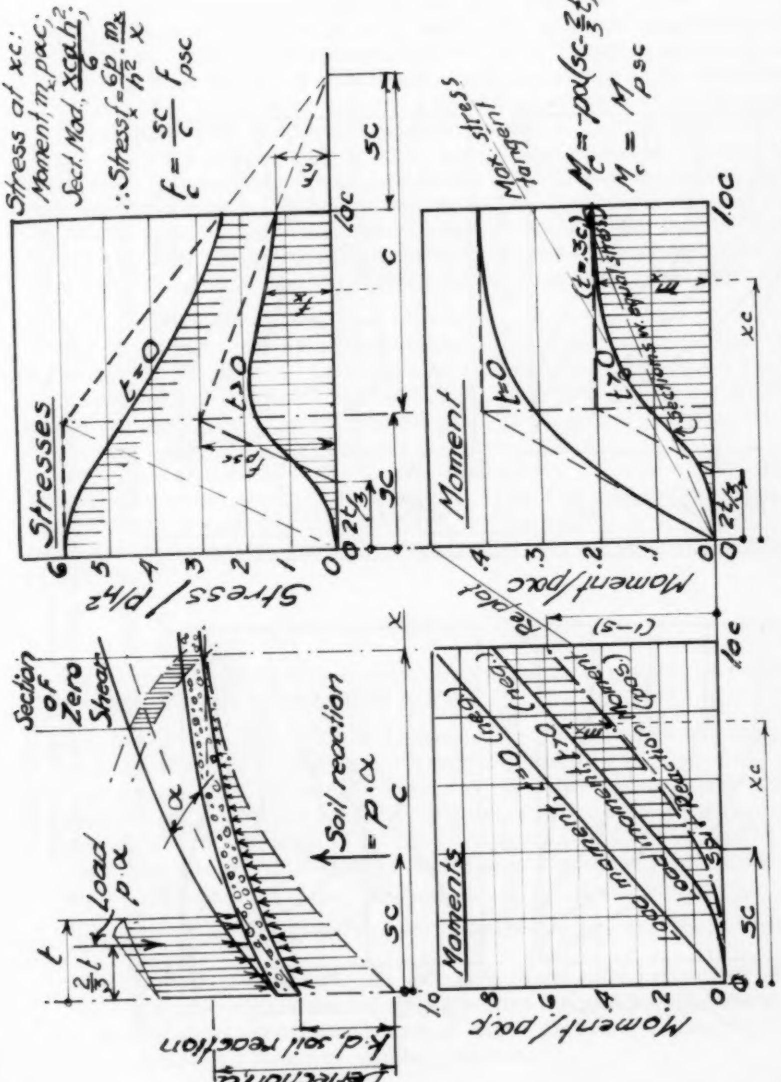


Fig. 4 Computation of force moments and stresses for any decimal value of loaded sector, based on assumed soil pressure distribution, showing also stress factor beyond the soil reaction sector.

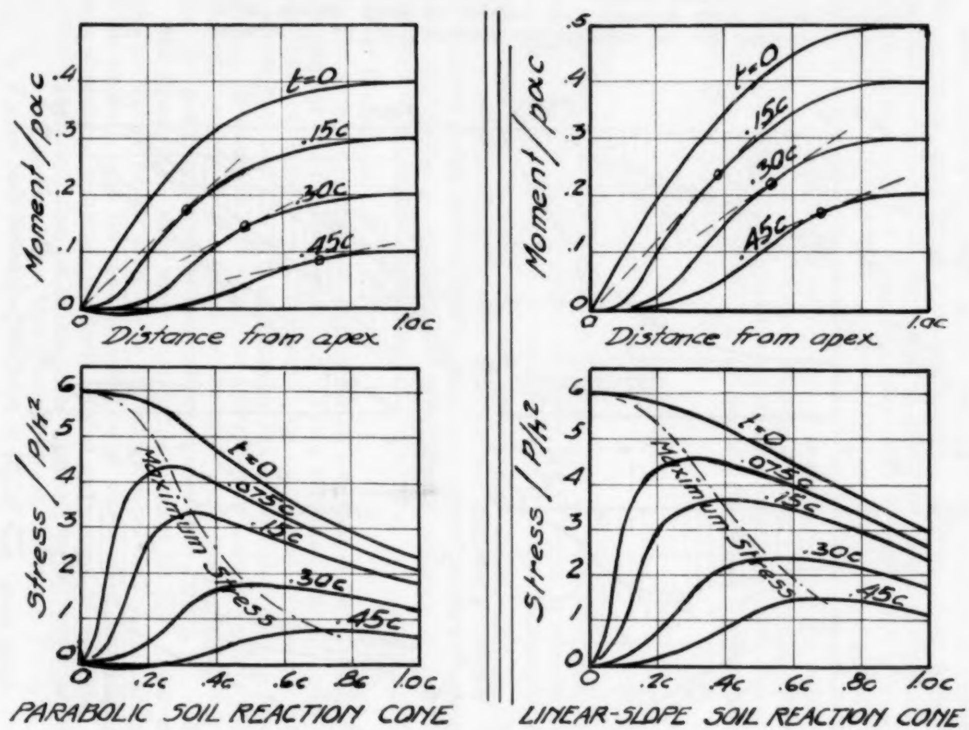


Fig. 5 Sector moment and sector stress curves without apex restraint for several tire load sectors, based on two assumed soil pressure distributions.

reaction sectors are obtained for the different sizes of wheel imprint in terms of slab properties and subgrade characteristics, as shown for one case in Fig. 6.

Sector Restraints

Conditions of equilibrium demand that each elemental sector can take flexural stress either at the apex or beyond the subgrade reaction sector, or both. Stress conditions at the apex are the more important as maximum stress may exist there. It was shown above that stress at the apex due to load component could occur only for a point load at the apex, and moment and stress conditions for such load are shown in Fig. 4. Sector Analysis presumes that apex restraint which is the condition of stress at the apex may be taken equal to a simulated point load at the apex, with moments and stresses away from the apex due to apex restraint the same as would occur for a point load at the apex. Stress curves due to apex restraints may then be plotted directly into the stress curves due to tire load and subgrade reaction to fit given conditions of geometry or stress, as is illustrated in the following.

Wheel Load Distribution

The total load on all elemental sectors must equal the wheel load. Vertical shears on the sides of the elemental sectors concentrated near their apex are taken into account as an approximation, by distribution of the wheel load on the principal elemental sectors unequally if necessary, to bring the apex deflections of the individual sectors to a common value.

A deflection curve has been assumed initially to obtain the first approximation of subgrade reaction distribution. From thus derived stresses an elastic curve is subsequently developed, and successive approximations may be necessary to obtain satisfactory agreement between assumed and derived elastic lines.

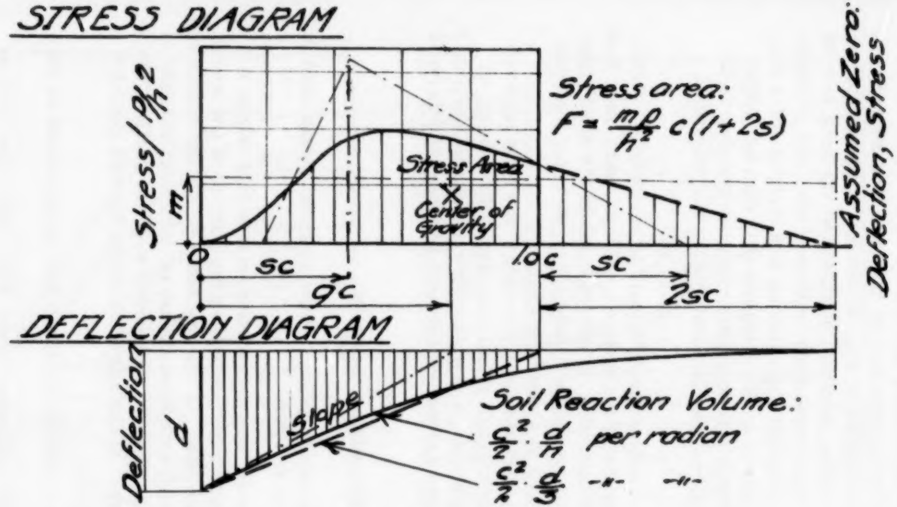
Terms, Definitions, Symbols

Before continuing to the numerical procedures the specific terms used in Sector Analysis will be defined as follows:

Soil Reaction Sector: This is defined as the elemental sector within a certain radius for which the soil reaction equals the portion of the wheel load acting on the elemental sector. At the soil reaction sector radius the shear on the sector arc is zero, with a maximum or minimum moment at that section, but because of the linearly increasing width of section, the maximum stress will be nearer to the apex. Symbols for soil reaction sector radii are:

- c - for elemental sectors of unlimited length and unrestrained at the apex;
- i - for elemental sectors of unlimited length fully restrained both at the apex and at some distance beyond the soil reaction sector;
- w - for short elemental sectors of length limited by a pavement edge, a symmetry plane, or similar condition.

The soil reaction sector radius and the location of the center of gravity of the reaction at radius sc or si, as the case may be, are the basis for estimating the total sector length extending beyond c or i, active in bending under load for long sectors, as will be shown.



Slope: $\dfrac{2F}{Eh} = \dfrac{2}{Eh} \cdot \dfrac{mp}{h^2} c\,(1+2s)$;

Deflection: $d = gc\,\dfrac{2F}{Eh} = p\,\dfrac{2mg}{E}\,\dfrac{c^2}{h^3}(1+2s)$;

Soil Reaction: $p = \dfrac{c^2}{2} \cdot \dfrac{d}{n}\, k = p\,\dfrac{k}{Eh^3} \cdot \dfrac{2mg\,(1+2s)}{2n}\, c^4$;

Soil Reaction Sector length: $c = \sqrt[4]{\dfrac{n}{mg\,(1+2s)}} \cdot \sqrt[4]{\dfrac{Eh^3}{k}}$.

Fig. 6 Computation of soil reaction sector radius for a typical sector stress curve extending an assumed distance beyond the soil reaction sector.

Tire Load Sector: This is the sector area within which the load acts on the sector at an assumed even intensity, and is here assumed equal to the distance from the apex covered by the tire imprint t, in which case the distance from the apex to the center of gravity of the load is $\frac{2}{3}$ t. For the initial computations of moments and stresses the tire load sector radius is taken as a decimal part of the soil reaction sector radius.

Distributed Sector Load: This is the term used for those proportionate parts of the wheel load, including compensation for shears, which are distributed to the different elemental sectors. The wheel load P is distributed over the total available slab angle to obtain the average sector load pave per radian, $\frac{2P}{\pi}$ for corner-loading, $\frac{P}{\pi}$ for edge-loading, and $\frac{P}{2\pi}$ for interior loading. Because of varying soil reaction sector radii and soil pressure distributions in different principal directions the soil reaction under these elemental sectors may not equal the tire pressures on the different sectors. Shear forces, largest near the apex, cause all sectors to deflect an equal amount at the apex. The distributed sector load p is that portion of the wheel load which equals the soil reaction under the elemental sector, and is determined from the condition that all elemental sectors must have the same deflection at the apex, regardless of horizontal dimensions.

Procedure for Long Sectors Unrestrained at Apex

Initial steps are illustrated for sectors unrestrained at the apex, with t a decimal value of c. It will be shown subsequently that they have application also to sectors restrained at the apex.

Moment and Stress Distribution

With the wheel load taken per unit of angle p, load moments and soil reaction moments can be directly plotted for any decimal value of t in terms of p c between the apex as origin and c. Fig. 4 shows the detailed procedures for an assumed deflection line, for concentrated load at the apex, t = 0, as well as for t larger than zero (t = .3 c illustrated). With no restraint at the apex, the total resulting moment is the difference between the soil reaction moment (positive) and the tire sector load moment (negative). The resulting moment diagrams are typical. The flexural stress (compression in top fiber positive) is obtained by dividing the moment by the section modulus, which for the constant slab depth k increases in direct proportion to the arc, any two points on the moment diagram intersected by a line from the origin therefore have the same stress, and the maximum flexural stress is at a point on the moment diagram tangent with a line from the origin. Stresses are expressed in units of p/h^2.

Fig. 5 shows two groups of moment and stress diagrams, each for several values of tire load sector, one group for parabolically decreasing soil reaction, the other for linearly decreasing soil reaction from the apex to zero at c. It is seen that stress exists at c, with zero stress accordingly some distance beyond c, and downwardly concave elastic line and maximum stress curvature between the apex and c. The reactive negative moment at c is

provided by uplift of parts of the slab some distance beyond c, with corresponding displacement of support for those parts of the slab toward c; some downward slab deflection must accordingly exist at c with downwardly concave curvature some distance beyond c, and some deflections upward. Moments and stress values for linear-slope reaction cones represent the closer first approximation of the two groups of curves in Fig. 5.

Slab Bending Beyond the Soil Reaction Sector

In long slab sectors as reasoned above, slab deflections, soil reactions, and slab stresses can be expected to decrease gradually to insignificant values some distance beyond the soil reaction sector. A convenient approximation of the additional length of sector in bending is suggested by sector stress relations, as follows:

The moment at c, Fig. 4, is p(c - sc) - p(c - 2t/3), or -p(sc - 2t/3); which is also the moment of the tire sector load alone at radius sc. The stresses for tire sector load alone at radius sc and for the total moment at radius c are accordingly related as c/sc. This geometric linear relationship shows a common zero-stress point at c + sc for all values of t, and has been traced in the stress diagram of Fig. 4; it shows that the stress at c may be represented as due to the moment of an exterior reactive restraining force at a constant distance sc beyond c for any value of t. Such a force would be the result of slab uplift for a cantilever extending about twice as far. For a gradual decrease in stress beyond c in long sectors the corresponding zero stress point is conveniently assumed at a distance of 2sc beyond c, also independent of the size of the tire load sector, (except insofar as the size of the tire load sector may influence the value of sc). Linear decrease in both sector stress and deflection and slope to zero at a distance of 2 sc beyond the subgrade reaction sector has been assumed for Sector Analysis applications of long sectors outlined below. For shorter sectors deflections and distributed loads must be adjusted to provide stress at c, no greater than can be resisted by uplift within available slab dimensions.

Quantitative Values of Soil Reaction Sector Radius

A typical stress diagram in accordance with the above outlined procedures for a specific decimal value of t is shown in Fig. 6 for a sector unrestrained at the apex. The pavement slope at the apex may be represented by the area under the stress diagram; the deflection at the apex, d, is represented by the said slope projected from the center of gravity of the stress area; in similar fashion the entire elastic line for the sector may be drawn, which is representative if in good agreement with the originally assumed variation in subgrade reaction.

The numerical soil reaction radius may be computed from the elastic line; the steps of computation have been shown in Fig. 6. They can be carried out most easily by estimating directly from the graphs the average or median stress mp/h^2, the distance from the apex to the center of gravity of the stress area gc, and the volume of elastic line soil pressure cone per radian of angle $c^2d/2n$. For linear relation between deflection and soil reaction the deflection cone volume with the soil reaction sector as a base, multiplied by the subgrade modulus k, equals the distributed sector load. The elastic-line deflection is proportionate to the load, the soil reaction sector radius is

therefore independent of the load. As derived in Fig. 6, it is represented by the following formula:

$$c = \sqrt[4]{\frac{n}{mg(1+2s)}} \sqrt[4]{\frac{Eh^3}{k}} \quad ; \tag{1}$$

where E is the modulus of elasticity of the concrete, h its depth, and k the modulus of subgrade reaction. The factor $\sqrt[4]{\frac{Eh^3}{k}}$ is a basic dimension characteristic for pavement elasticity, depth, and support, for which will be used the symbol R.

The computations shown in Fig. 6 for one decimal value of t may be repeated for different values of t as shown in Fig. 7, including the concentrated load condition t = 0. The soil reaction radius for long sectors unrestrained at the apex is found to approximate 1.0 R for t = 0, increasing to near 1.15 R for large decimal values of t. Groups of curves have been drawn in Fig. 8, giving the numerical relationship between tire load sectors as ordinates and soil reaction sector radii as abscissas, for 4,000,000- and 5,000,000-psi. concrete modulus of elasticity, for 4-, 6-, 8-, and 10-in. slab depths, and for 100-, 200-, and 400-psi. per inch deflection (abbr- pci.) subgrade modulus. The tire load sector dimension is obtained directly from design wheel dimensions placed near the corner; for any given subgrade, concrete, and slab depth the corresponding actual value of soil reaction sector may be read in the diagram Fig. 8.

For any specific decimal value of tire load sector the critical stress in terms of p/h^2, as well as the critical section in terms of c may be obtained directly from the stress diagrams such as shown in Fig. 5. For convenience the values of critical stress and location of critical section have been replotted in a separate diagram in Fig. 8 for decimal values of tire load sector as abscissa, both for linear- and parabolic- change in soil pressure. As shown by Fig. 8 soil reaction sector radii do not change greatly for normal sizes of highway tires, but the maximum stress is very much dependent upon the size of tire load sector.

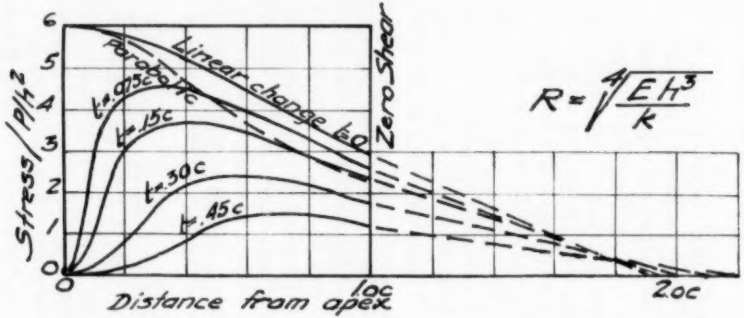
The elastic line developed from stress computations as shown in Fig. 6 may be the basis for a second approximation of deflections and distance to soil reaction center of gravity. For any given design wheel load, say 10,000 lb., also non-linear relation between deflection and soil pressure may be investigated, based on this and further approximations of deflections.

In the foregoing procedure soil reaction deflection-cone volume per radian of angle has been expressed as: $\frac{c^2}{2} \cdot \frac{d}{n}$, following conventional analogy, which would give n-values of $\underline{6}$ for parabolic elastic line, $\underline{3}$ for straight slope, and $\underline{1}$ for constant deflection; usual values of n appear to be from 2.5 to 3.5.

Procedure for Long Sectors Restrained at Apex

Stress exists directly under the load at the apex of principal sectors under conditions of continuity to sectors in opposite direction. For such conditions, in addition to the stress components of tire load and soil reaction the further stress components due to apex restraint and its soil reaction must be included.

$$R = \sqrt[4]{\frac{Eh^3}{k}}$$



$$c = \sqrt[4]{\frac{n}{mg(1+2s)}} \cdot \sqrt[4]{\frac{Eh^3}{k}} = \sqrt[4]{\frac{n}{mg(1+2s)}} \cdot R$$

t	Estimated values: n	s	m	g	$\sqrt[4]{\frac{n}{mg(1+2s)}}$
0	3.5	.45	3.0	.60	1.0
.075c	3.3	.48	2.3	.70	1.02
.15c	3.2	.50	1.9	.75	1.05
.30c	2.9	.55	1.2	.85	1.10
.45c	2.6	.60	.75	.95	1.15

n: Reaction, $\frac{c^2}{2} \cdot \frac{d}{n}$;
m: Mean stress, $m\frac{p}{h^2}$;
g: Stress area center of gravity, gc;
s: Soil reaction centered at sc;
t: Tire load sector.

Fig. 7 Variables determining the soil reaction sector radius in long sectors without apex restraint.

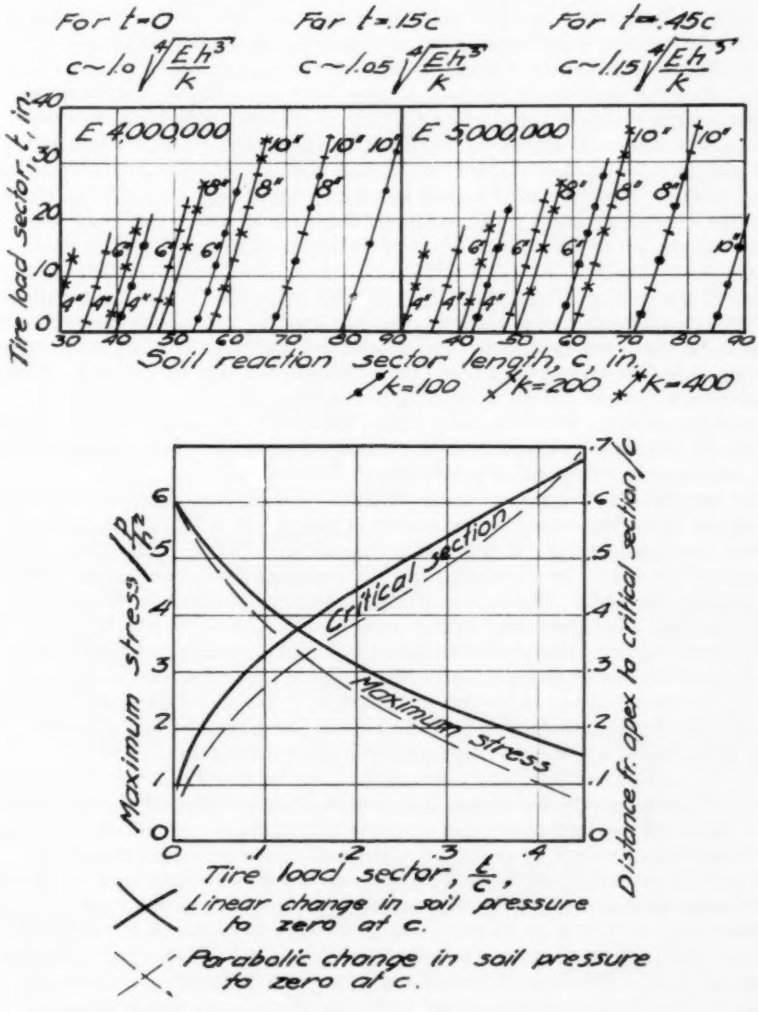


Fig. 8 Soil reaction sector radii in long sectors without apex restraint for tire load sectors up to 40 in., 4- to 10-in. slabs of two elastic moduli, on 100- to 400-pci. subgrade; also maximum stresses and critical sections.

The stress diagrams in Fig. 4 and Fig. 5 show that there is no stress at the apex except for load concentrated at the apex. Stress at the apex and load at the apex may then be treated as similar sector conditions. It is logical to assume that stress away from the apex due to restraint—stress—at the apex varies as it would for a simulated and upwardly directed load at the apex, except that the simulated vertical load would have its own deflections to be applied as correction to deflections for an assumed unrestrained sector such that the adjusted deflections could be applied for the subgrade reaction distribution under the restrained sector. It appears to be a closer and certainly simpler approximation, then, to take tire load stress-, subgrade reaction stress-, and restraint stress-components as computed directly from deflections assumed for restrained sector. Component stresses at any section due to restraint at the apex are obtained simply by applying a proportionality factor to the stresses for $t = 0$ in the stress diagram for other decimal value of t, based on an acceptable assumption of deflection line for the restrained sector.

The above rule may be stated: The change in sector stress due to apex restraint is assumed to be the sector stress for fractional load concentrated at the apex; the fractional factor is so selected that the resultant total-stress diagram satisfies stress conditions for symmetry or end limitations. Estimation of slab length active in bending beyond the soil reaction sector is based on geometric relations which apply also for $t = 0$, and therefore also to the sum of the stress components in restrained sectors. Zero stress, deflection, and slope is assumed at a distance of 2 si beyond i.

The application to symmetrically opposed long sectors, such as for interior loading far from any edge, is illustrated in Fig. 9 for one specific decimal value of tire load sector. A horizontal tangent must exist at the apex and also at distance $i + 2si$. The stresses for apex restraint are positive, opposed to the stresses for load. The stress component curve due to restraint is so drawn, in Fig. 9, proportional to the stress curve for $t = 0$, that the positive stress area representing upwardly concave curvature near the apex equals the negative stress area for downwardly curving slab portions further away. The maximum stress is at the apex, and equal to the restraint stress, shown directly for the distributed load on the sector, for each specific decimal value of tire load sector, as illustrated for one value in Fig. 9.

An elastic line for the restrained sector may be derived from the stress areas, as indicated for the stress diagram in Fig. 9, using the stress area-slope relations outlined above for unrestrained sectors. As before, the stress areas and their centers of gravity and the soil reaction sector deflection-cone volume are easily estimated directly on the stress diagrams. A quantitative value of soil reaction sector radius in terms of R is obtained for each decimal value of tire load sector. The procedure is repeated for different decimal tire load sectors, and quantitative values of i in terms of R obtained, except for $t = 0.1$ (The value of i for $t = 0$ has been derived by considering the change in the elastic line due to the restraint alone, from deflections and soil pressures of the unrestrained sector to those for the restrained sector, without the simplifying shortcut of direct use of stress diagrams applied to other decimal t-values.)

Comparing Fig. 6 and Fig. 9, it is seen that the stress diagrams for unrestrained and apex restrained sectors differ radically; however, the positive stress near the apex influences only a very limited portion of the soil reaction deflection-cone volume. Soil reaction distribution for a straight

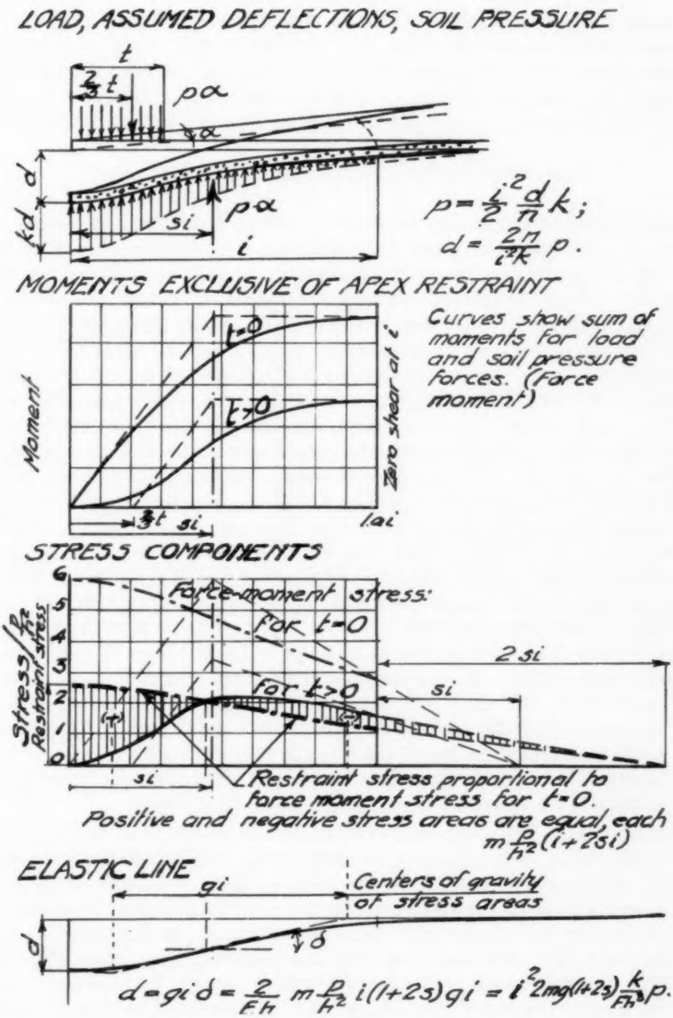


Fig. 9 Application of concentrated apex-force moment and stress curve to restraint stress determination, illustrated for a long sector restrained to zero slope at the apex and at the outer end.

sided cone therefore appears to be sufficiently close first approximation also for sectors restrained at the apex. Actual n-values would be about 2.5.

The soil reaction sector radius for long fully restrained sectors approximates 1.5 R, for t = 0, and somewhat less for larger decimal values of t. Related values of tire load sector and soil reaction sector radii applicable to long sectors fully restrained, have been plotted in Fig. 10 for the same pavements and properties represented in Fig. 8. A diagram for maximum stress, at the apex, as taken directly from stress diagrams for different decimal values of tire load sector (one point shown in Fig. 9), is also shown in Fig. 10.

Restraints and End Conditions in Short Sectors

By short sectors are meant sectors extending from the apex some specific dimension to slab ends or edges, less than the maximum sector length assumed to be bending under load. Widths of conventional pavement lane slabs are not usually sufficient for end restraints of transverse sectors. The length of these elemental sectors is the distance from the wheel center to the edge or to some symmetry or zero shear plane near the center of the pavement lane or the axle. Transverse sector stresses are dependent upon these dimensions. For normal highway pavement lanes and axle loads as shown in Fig. 3, with each wheel about 3 ft. from lane center and from the edges, constant deflection and soil pressure intensity would come close to actual conditions for transverse sectors. Stress conditions for long sectors unrestrained at the apex may on the other hand be approximated for elemental sectors perpendicular to the edge for single-wheel edge-loadings. Transverse sector stress must be zero at the slab edge. For the transverse sector between a wheel center and an adjacent edge some specific distance away, apex restraint stress can be obtained directly on stress diagrams drawn for distributed load p and approximately correct soil pressure distribution, by drawing in the stress curve proportional to that for t = 0, so as to give zero stress at the end of the sector. For a wheel load near the center of a normal highway pavement lane, the edge deflection may be very small; linearly decreasing soil pressure distribution to zero would be a sufficient first approximation for such transverse sectors, but for shorter sectors for wheels at quarter points transversely constant soil pressure may be more nearly correct to obtain the subgrade-pressure moment and stress component.

Stress diagrams for short sectors are shown in Fig. 11, one graph for linearly decreasing soil pressure to zero at W_o, one graph for constant soil pressure. Restraint stress conditions may be applied in these stress diagrams, proportional to the stresses for t = 0, to fit physical limitations, in Fig. 11 shown for the condition of zero edge stress. In the constant-pressure sector diagram, for .45w and .60w tire load sectors, are shown also conditions of full restraint both at the apex and at W, such as would apply approximately for a short sector to the center of a symmetrically placed axle, with positive and negative stress areas about equal. Applicable to stress diagrams shown for soil pressure decreasing linearly to zero at W_o, the sector lengths for zero stress and deflection at the end is found to approximate 1.3 R for t = 0, decreasing slightly to about 1.2 R for large decimal t-values. Numerical values of tire load sectors and these zero-deflection sector lengths are shown in diagrams in Fig. 11 for slabs of dimensions and properties same as in Fig. 8.

Specific sector lengths substantially shorter than the dimensions in Fig. 11 may be assumed to have approximately constant deflection between the apex

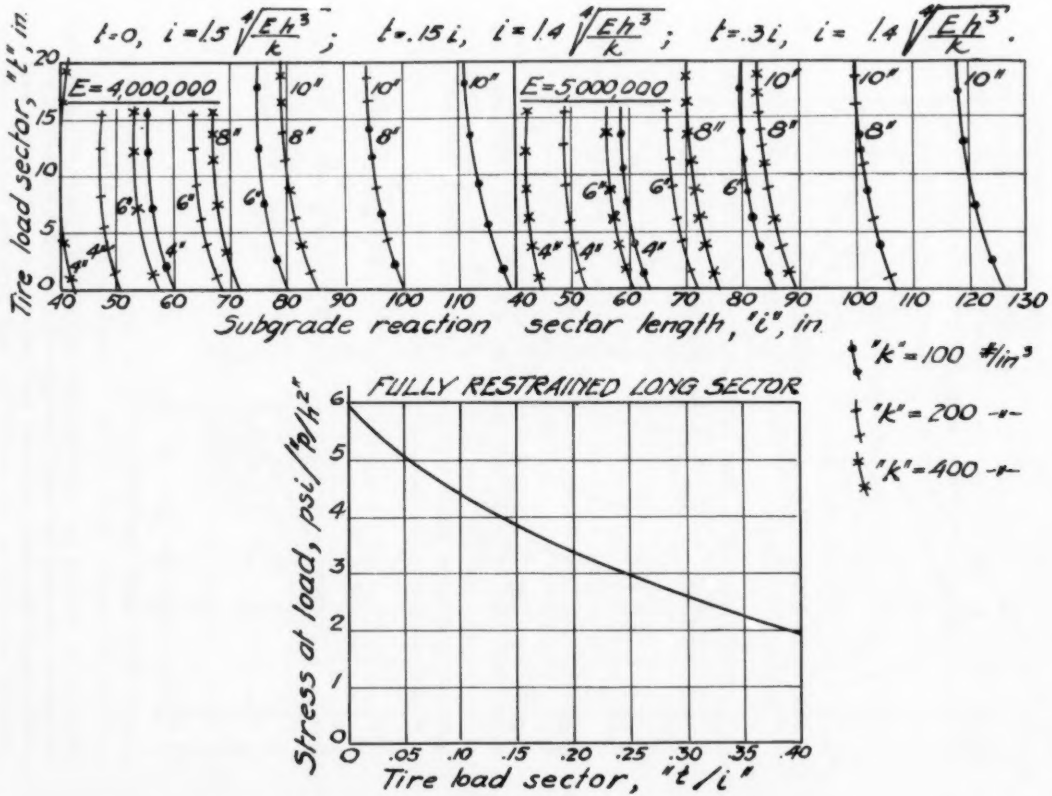


Fig. 10 Soil reaction sector radii of long fully restrained sectors for tire load sectors up to 20 in., 4- to 10-in.slabs of two elastic moduli, on 100-

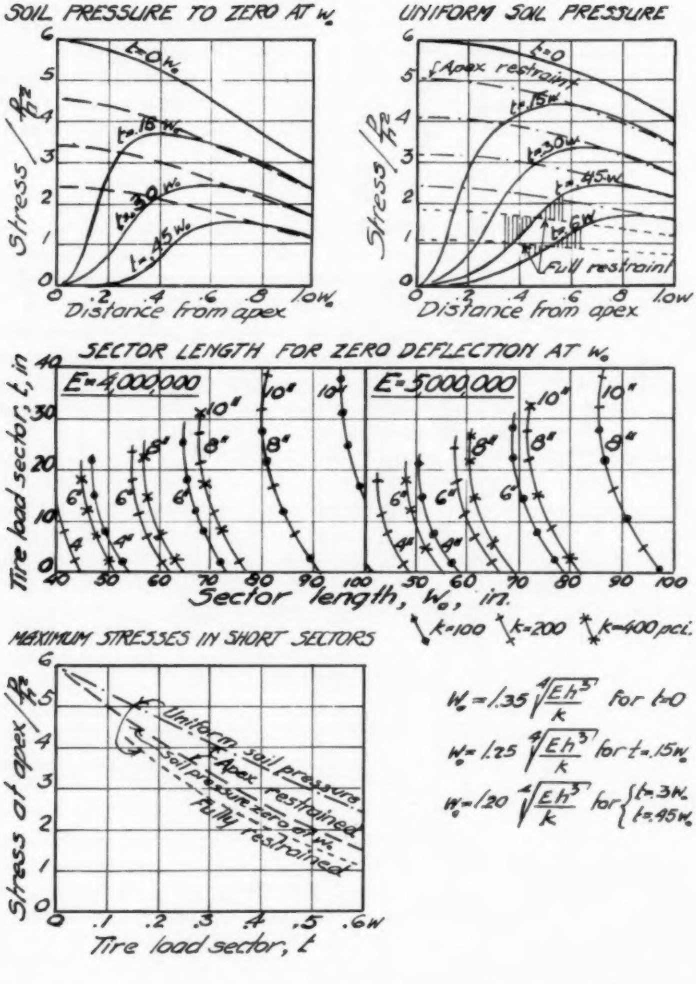


Fig. 11 Stresses in sectors for soil pressure decreasing linearly from the apex to zero at the end, and radii for zero end deflection when fully restrained at the apex; stresses in short sectors for uniform soil pressure with apex or full restraint; apex stresses in short sectors.

and the end; sectors longer than these dimensions would have stresses, deflections, and soil reaction sector radii, approaching those for long fully restrained sectors. Apex restraint stresses, as obtained directly from the stress diagrams, have been plotted in relation to tire load sector in a separate diagram in Fig. 11 for zero-stress condition at the end of short sectors. Stress conditions intermediate to that for constant soil pressure and linearly decreasing soil pressure would generally apply to transverse pavement lane sectors. In comparing the apex stresses for these conditions, it must be remembered that the decimal value of any one tire load sector would be different for the different sector dimensions, and the distributed load acting on the sector must be adjusted to equal the subgrade reaction.

Distributed Sector Load

In all stress diagrams, sector stresses are expressed in terms of p/h^2. for the equilibrium condition that the load on the sector equals the soil reaction under that sector. The vertical shear forces on the sides of the sectors, which effect any necessary redistribution of tire loads between the principal elemental sectors to attain this equilibrium for an apex deflection common to all sectors, are assumed to be acting in the same manner as the tire load localized within the tire load sectors. There is obviously no mathematical justification for such an assumption, other than the obvious concentration of shears near the apex, it is made to attain the simplicity of a single sector stress computation for any decimal value of tire load sector.

When the soil reaction sector radii, or specific sector dimensions and soil pressure distribution have been obtained with sufficient accuracy, the wheel load is distributed on the different principal sectors. Subgrade reaction sector radii may vary in different directions because of differences in pavement depths, subgrade variables, or non-circular tire imprint dimensions, but all sectors have the deflection d at the common apex. For two elemental sectors with apex angle α and subgrade reaction radii c_1 and c_2 the subgrade reactions are $\frac{\alpha c_1^2}{2} \cdot \frac{d}{n_1}$ and $\frac{\alpha c_2^2}{2} \cdot \frac{d}{n_2}$, which equal the distributed sector loads p_1 and p_2 per radian for the angle α, respectively, giving the relation:

$$\frac{p_1}{p_2} = \frac{c_1^2 \, n_2}{c_2^2 \, n_1} . \tag{2}$$

If the deflection cone shape is substantially the same in the different directions, the tire load is distributed on the different sectors in proportion to the square of the subgrade reaction sector radii.

For elemental sectors in two equal principal directions, the average sector load per radian, p_{ave}, which has been computed previously, determines numerical values of p_1 and p_2:

$$p_1 = p_{ave} \cdot \frac{2}{1 + \frac{c_2^2 \, n_1}{c_1^2 \, n_2}} ; \tag{3}$$

$$p_2 = 2p_{ave} - p_1 \quad . \tag{4}$$

For edge-loading the two longitudinal-direction restrained sectors, with soil reaction radius i, and distributed load p_i can be assumed to predominate over the single-direction sector perpendicular to the edge unrestrained at the apex with sector load p_c. Assuming simple arithmetical relation:

$$\frac{2p_i + p_c}{3} = p_{ave} \quad ;$$

Accordingly, from equation (2) and substituting i and n_i for the restrained edge sectors, the distributed sector loads, p_i along the edge, and p_c transversely, are obtained:

$$p_i = p_{ave} \cdot \frac{3}{2 + \frac{c^2 n_i}{i^2 n_c}} \quad ; \tag{5}$$

$$p_c = 3p_{ave} - 2p_i \quad . \tag{6}$$

The condition of very different soil pressure distribution in principal directions is shown in Fig. 12, showing the deflections for each wheel of a normal highway lane axle load. The short transverse sectors from the wheel to the slab edge on one side, and to the center of the lane and the axle on the other side, can be assumed to have constant deflection with soil reaction volume n_w -value of 1, compared to n_i -value of about 2.5 for the restrained longitudinal sectors. This loading is covered in a later example of Sector Analysis applications.

The approximate deflection under the load, as shown for corner soil reaction radius c in the following formula, is obtained directly from the soil reaction volume:

$$d = \frac{2np}{k c^2} \quad . \tag{7}$$

Further approximations of reactions can be applied to the elastic lines derived by Sector Analysis for first-approximations, including—for specific loads—non continuous soil pressures.

EXPERIMENTAL VERIFICATION OF SECTOR ANALYSIS

Sector Analysis contains numerous approximations and simplifying assumptions, the admissibility of which have not been appraised mathematically. However, a number of careful load tests for the corner-, interior-, and edge-loadings with single circular-area loads afford adequate opportunity for comparison of Sector Analysis computations with observed stresses and deflections. Tests for non-circular tire loads and axle loads are all but unknown, but the influence of variations in tire load sector dimensions can be deduced from the circular-area tests.

SECTOR LOAD:

$$p_{ave.} = \frac{P}{2\pi} = \frac{p_i + p_w}{2}.$$

SECTOR LOAD DISTRIBUTION:

$$p_i = \frac{i^2}{2} \cdot \frac{d}{n_i} \cdot k \;;$$

Average for transverse sectors:

$$p_w = \frac{w^2}{2} \cdot \frac{d}{n_w} \cdot k \,.$$

$$\left(p_w \sim \frac{w^2}{2} \cdot d \cdot k \right)$$

$$\frac{p_i}{p_w} = \frac{i^2}{w^2} \cdot \frac{n_w}{n_i} \,.$$

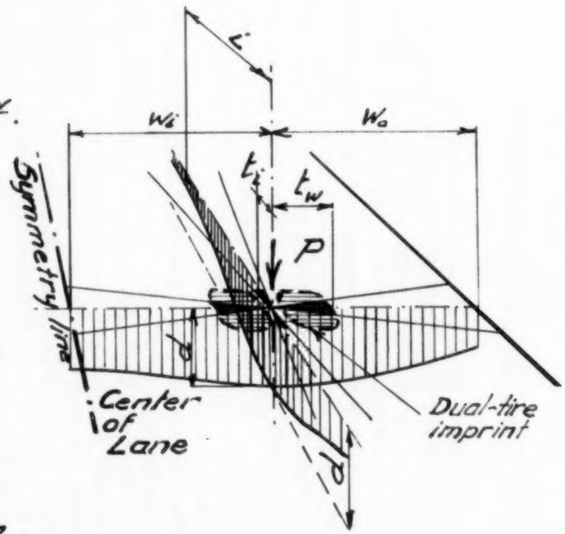


Fig. 12 Sector load distribution in principal directions for unequal soil reaction sector radii and soil pressure distributions.

Comparisons for the different representative load positions have been arranged in tabular form, Tables 1 to 4, incl. The procedural steps of Sector Analysis, applicable to the same loads, are illustrated step by step in these tables, with reference to the foregoing illustrations of this presentation. To aid study, the specific illustrations of the references from which the test data have been obtained are indicated by F., followed by figure numbers of the references.

Corner Load Tests and Computations

Corner load tests for circular loaded areas on slabs of different depths have been reported by Teller and Sutherland.(4) Maximum stresses derived from observed strains along the bisector, distances to the critical sections, and corner deflections, as taken from applicable reference illustrations, are given in Table 1. Computation of the corresponding data by Sector Analysis, based on approximations given in Part II, are also shown in Table 1, with subgrade modulus determined to fit the observed deflections. The agreement between tests and computations of stress along the bisector is satisfactory for the 9-in. slab and for large loaded areas on the 6-in. slab, less so for loads near the corner on the 6-in. slab; however, the experimental observations also varied considerably.

Spangler and Lightburn(6) have reported deflection and stress observations for a 6-in. slab placed on a prepared subgrade, loaded to 5,000 lb. on different circular areas near corners. The observed modulus of elasticity was 4,000,000 psi., the subgrade modulus was measured with pressure cells, it was 300 pci. at the corner and less than 200 pci. for pressure cells over 15 in. from the corner. Table 2 shows the test data obtained from indicated illustrations in reference (6), together with Sector Analysis computations of stress, critical section, and corner deflection, based on a subgrade modulus of 250 pci. The agreement between tests and Sector Analysis computations is satisfactory.

All tests indicate maximum stresses away from the two edges, over a fairly wide area at and near the bisector for full-circle loads. In computing the load distribution and the diagonal maximum stress, the increased distance from the corner covered by the tire along the bisector has been taken into account. Sector Analysis values of stress would be somewhat greater along the edges because of center of tire pressure closer to the corner and the smaller decimal value of tire load sector along the edges. For loaded areas of substantially non-circular outline, Spangler and Lightburn observed maximum strains between the bisector and the edges, as shown in Fig. 9, b, of reference (6). The relative change in maximum stress with increase in tire contact was in general agreement with the stress curve of Fig. 8. Sector Analysis appears to give a reasonable approximation of corner load stresses and deflections, and of the effects of varying the size of loaded area.

Interior Loading Tests and Computations

Deflection and stresses for 4- to 10-in. radius loads at center of 10 ft. wide 6- to 9-in. slabs have been reported by Teller and Sutherland.(4) Experimental values are compared with longitudinal and transverse values of stress and deflection as computed by Sector Analysis in Table 3, for small and large load areas on 6- and 9-in. pavements, assuming the observed stress

Table 1. Comparison of Corner load tests by Teller and Sutherland (4) for 8- to 20-in. diameter circular loads on 6- and 9-in. slabs with Sector Analysis computations, based on E 4,000,000 psi., of first-approximation values of deflection, stress, and distance to critical section.

Item:	Ref.	Unit:	Test data and Computations:					
TEST DATA: h			6-in. slab			9-in. slab		
Corner load	F. 35	lb.	7,000			15,000		
Circular area diameter	F. 35	in.	8	12	20	8	12	20
Observed stress, bisector	F. 35	psi.	320	280	200	420	360	280
Dist. to critical section	F. 17	in.	25	30	40	25	35	45
Observed deflection	F.(19 (27	in.		.065			.075	
SECTOR ANALYSIS COMPUTATIONS, (Subgrade modulus k = 150 psi./in. defl.[1])								
Average sector load		lb./rad.	4,450			9,550		
Estimated tire load sector:								
along edge, (average)		in.	8	12	20	8	12	20
along bisector, t		in.	9	14	23	9	14	23
Soil reaction sector:	Fig.8							
along edge		in.	52	53	56	69	71	74
along bisector, c		in.	53	54	57	70	72	75
Distributed sector load:	eq.(3)							
edge sector		lb./rad.	4350	4350	4400	9400	9400	9400
diagonal sector, p		lb./rad.	4550	4550	4500	9700	9700	9700
Decimal tire sector, diag.		t/c	.17	.26	.40	.13	.20	.31
Diagonal Maximum Stress:	Fig.8	p/h^2	3.3	2.6	1.8	3.7	3.1	2.3
computed for p, and h		psi.	420	330	220	440	370	280
Computed/observed stress			131%	118%	110%	105%	103%	100%
Distance to critical section:	Fig.8	c	.4	.5	.65	.35	.45	.55
		in.	21	27	37	25	32	41
Corner Deflection	eq.(7) (n = 3)	in.	.065	.063	.055	.079	.075	.069

NOTE: [1] Subgrade modulus chosen to fit observed deflections (extrapolated) for 12-in. diameter circular load, with soil reaction volume per radian $\frac{c^2}{2} \cdot \frac{d}{3}$.

Table 2. Comparison of Corner load tests by Spangler and Lightburn (6) for 3- to 11.5-in. diameter load on 6-in. slab with Sector Analysis computations, based on E 4,000,000 psi., of first approximation values of stress, critical section, and deflection.

Item:	Ref.	Unit	Test & Computation		
TEST DATA: 6-in. slab h		in.	6		
Corner load		lb.	5,000		
Circular loaded area, diameter	F. 8	in.	2.94	6.72	11.5
Distance, corner to center	F. 8	in.	2.87	4.75	8.13
Maximum strain	F. 8	$1/10^{-6}$	90	75	50
Stress for E 4,000,000		psi.	360	300	200
Distance to critical section	F. 8,18	in.	10-15	20	17-20
Corner deflection	F. 14	in.	.042	.036	.031
SECTOR ANALYSIS COMPUTATIONS	(based on subgrade modulus 250 pci.)				
Average sector load		lb./rad.	3,180		
Estimated tire load sector:					
along edge		in.	4	6	11
along bisector t		in.	4 1/4	7 1/2	13
Soil reaction sector:	Fig. 8				
edge sectors		in.	44	45	47
diagonal sector c		in.	44	46	48
Distributed Sector Load:	eq.(3)				
edge sector		lb./rad.	3180	3110	3110
diagonal sector		lb./rad.	3180	3250	3250
Decimal tire sector, diag.		t/c	.10	.16	.27
Diagonal Maximum Stress:	Fig. 8	p/h^2	4.2	3.5	2.5
computed for p and h		psi.	370	315	225
Computed/observed stress			103%	105%	112%
Distance to critical section:	Fig. 8	c	.3	.4	.5
		in.	13	18	24
Corner Deflection	eq.(7) (n = 3)	in.	.039	.037	.034

Table 3. Comparison of interior load tests by Teller and Sutherland for 8- to 20-in. diameter circular loads on 6- and 9-in. slabs with Sector Analysis computations, based on E 5,000,000 psi., of first-approximation values of longitudinal and transverse stress.

Item:	Ref.	Unit:	Tests and Computations			
TEST DATA: h			6-in. slab		9-in. slab	
Interior load		lb.	7,000		15,000	
Loaded area radius	F. 40	in.	4	10	4	10
Observed stress	F.40,41	psi.	210	120	250	140
Observed deflection	F. 28 / 23		.007		.007	
SECTOR ANALYSIS COMPUTATIONS						
Average sector load		lb./rad.	1,120		2,400	
Subgrade modulus			200		250	
Tire load sector t		in.	4	10	4	10
Soil reaction sectors						
longitudinal i	Fig. 10	in.	69	67	91	89
transverse, actual		in.	60	60	60	60
to 0-deflection w_o	Fig. 11	in.	63	60	82	79
Adjusted load, transverse		% of p_{w_o}	99	100	85	88
Distributed sector load	eq.(3)					
transverse p_w		lb./rad.	1000	1000	1800	1850
Longitudinal p_i		lb./rad.	1240	1240	3000	2950
Longitudinal stress:						
decimal tire sector		t/i	.06	.15	.045	.11
relative stress	Fig.10	p/h^2	4.9	3.9	5.2	4.2
stress for p and h		psi.	170	135	190	150
Transverse stress:						
decimal tire sector		t/w_o	.06	.17	.05	.13
relative stress	Fig.11	p/h^2	5.4	4.5	5.5	4.8
stress for p and h		psi.	150	125	120	110
Computed deflection (n 2.5)	eq.(7)	in.	.0065	.0070	.0072	.9974
Longitudinal stress, adjusted for $\mu = .15$		psi.	197	158	213	170
Computed / observed stress			95 %	130 %	85 %	120 %

Table 4. Comparison of edge-loading tests by Teller and Sutherland with Sector Analysis Computations of first-approximation values of stresses. Modulus of Elasticity for 6-in. slab 4,000,000 psi., 9-in. slab 5,000,000 psi., approximate observed properties.

Item:	Ref.	Unit:	Tests and computations			
<u>TEST DATA</u>: (Ref.4) h			6-in. slab		9-in. slab	
Edge load		lb.	7,000		15,000	
Loaded half-circle radius	F. 42	in.	4	10	4	10
Observed stress		psi.	360	250	350	280
Observed deflection	F. 26, 29	in.	.024		.020	
<u>SECTOR ANALYSIS COMPUTATIONS</u>						
Average sector load		lb./rad.	2,230		4,780	
Subgrade modulus		pci.	100		150	
Tire load sector t		in.	4	10	4	10
Soil reaction sectors:						
longitudinal l	Fig. 10	in.	77	76	104	102
transverse c	Fig. 8	in.	55	57	72	73
Distributed sector load: (n_l 2.5, n_c 3.0)						
longitudinal p_l	eq.(5)	lb./rad.	2760	2710	5970	5900
transverse p_c	eq.(6)	lb./rad.	1200	1300	2400	2450
<u>Longitudinal stress:</u>						
decimal tire sector		t/l	.05	.13	.04	.10
relative stress	Fig. 10	p/h^2	5.0	4.0	5.2	4.4
stress for p_l and h		psi.	380	300	380	320
Computed / Observed stress			105 %	120 %	108 %	114 %
<u>Transverse stress</u>, tension in top surface:						
decimal tire sector		t/c	.07	.18	.05	.14
relative stress	Fig. 8	p/h^2	4.5	3.3	4.8	3.6
Stress for p_c and h		psi.	150	120	140	110
Observed Stress (Ref. 7) (prorated from 6,000-lb. load)	F.6	psi.		140		
Computed Deflection	eq.(7)	in.	.023	.024	.018	.019

to be longitudinal stress. Subgrade modulus values have been chosen to obtain computed deflections about equal to those observed, assuming n-value of 2.5 and E 5,000,000 psi.

Longitudinal sectors are fully restrained, transverse sectors only at their apex. The transverse sectors for 9-in. slabs are substantially shorter than lengths corresponding to zero deflection at the end as shown in Fig. 11; the load distributed to transverse sectors has accordingly been adjusted downwardly to compensate for the decreased deflection volume, soil reaction, and curvature of these sectors. In comparing experimental and computed stress values it should be remembered that Poisson's ratio has been applied to stress computations from the observed experimental strains but not to the computed sector stresses. Computed stresses in transverse direction are lower than those in longitudinal direction. If a Poisson's ratio of .15 is applied to computed longitudinal stresses shown in Table 3, they would be from 15 percent below to 30 percent above the observed stresses. Sector Analysis, while in good average agreement, apparently underestimates the decrease in stress with increasing tire imprint.

Edge-Loading Tests and Computations

Teller and Sutherland have reported deflection and longitudinal stress measurements for 4- to 10-in. half-circular loads at the edge of 6- to 9-in. slabs,(4) and transverse stress measurements as well for a load centered 6 in. from the edge.(7) In Table 4 these experimental values for the smallest and largest loaded radii on 6- and 9-in. slabs are compared with Sector Analysis computations. Subgrade modulus values have been chosen to obtain computed deflections about equal to those observed for 4,000,000-psi. modulus of elasticity of the 6-in. slab, and 5,000,000 psi. of the 9-in. slab.

Computed edge sector stress values are from 5 to 20 percent greater than observed and the computed transverse stress somewhat lower than observed, with the greatest deviation for the longest tire load sectors. Actual flexure conditions are apparently adequately simulated by Sector Analysis, assuming fully restrained sectors with top-surface compression at the load along the edge, and the transverse sector unrestrained at the apex with maximum stress tension at the top surface about 2 ft. from the edge.

Review

The examples of Tables 1 to 4 illustrate the procedures of Sector Analysis in computation of stresses and deflections for representative single circular loaded areas. The general agreement with experimental values shows that the concepts of Sector Analysis approximate adequately the action of slabs on subgrades loaded by tire imprints; this applies especially to the concepts of soil reaction sector and tire load sector, of the apex restraint as simulated by concentrated apex load stress, and of the principle of distributed sector load.

Referring specifically to the tabular examples, first-approximation computations for all load conditions are close to observed stresses for both small and large imprints on 9-in. slabs, and are sufficiently close for small imprints on 6-in. slabs if the corner load tests of Table 2 are accepted as representative. The agreement with longitudinal stresses in 6-in. slabs for large-imprint edge or interior loadings is less satisfactory. Related to

increasing size of tire-load area, Sector Analysis represents closely the corresponding decrease in diagonal stress for corner loads, but shows less than observed decrease in stress for interior and edge loadings. The explanation undoubtedly lies in the apex restraint stress simulated by point stress at the apex only, as too rigid an assumption for increasing size of tire load areas.

The observed lengths of slab bending in flexure under load, especially for edge and interior loadings, were shorter than the distances assumed in Sector Analysis, (soil reaction sector length plus twice the radius of soil reaction center of gravity). The bending of the experimental slabs would have been approximated more closely by a bending sector length assumed to extend beyond the soil reaction sector radius half as far as assumed in Part II; such an assumption would result in decreased apex stresses and increased negative stresses, with somewhat better experimental agreement. However, full appraisal of these conditions would require experimental observations of stress away from points of loading.

Refinements of assumptions as to active length of sector bending, and adjustments for shears, as well as determination of n-values for all possible soil reaction cones and soil pressure distributions, are not included in this paper. For normal highway loadings acceptable results appear obtainable even on first approximations. For the larger tire imprints of aircraft loadings experimental data are needed for comparison.

SOME APPLICATIONS OF SECTOR ANALYSIS

The following illustrations show the application of Sector Analysis to common highway load conditions.

Single-Axle Lane Loading

The axle lane loading condition is defined by an axle load with the wheels about equally spaced from the sides of a pavement slab and sufficiently far from the ends that interior load curvatures apply to longitudinal sectors. The normal single-axle truck loading on a 12-ft. wide highway pavement imposes two wheel loads at the quarter points of the slab, as shown in Fig. 13. The exterior transverse sectors, w_o, and the interior transverse sectors to the center of the land, w_i, are all 36 in. long. The tire load sectors for dual tires would be 6 in. for longitudinal sectors and 10 in. for transverse sectors, or .28 w.

As a sufficient first-approximation for normal pavement depths the soil pressure can be assumed constant under the transverse sectors as shown in Fig. 13. The stress under the wheel for the outside sector, if fully restrained at the apex, would be about 4.3 p/h^2 for $t/w = .28$ according to Fig. 11. If the inside sector is assumed fully restrained both at the apex and at the symmetry line the stress under the wheel in the inside sector would be 2.9 p/h^2. The same apex stress must exist for these two sectors meeting at the common apex, which corresponds to a somewhat different transverse deflection line, depressed toward the center, decreasing the soil reaction under the outside sectors with equivalent increase under the inside sectors, accompanied by inward tilt of the tangent under the wheel and some increase in positive stress area of the inside sector, for which the tangent at the center of the lane must still be horizontal. The adjustments in soil reactions and stresses

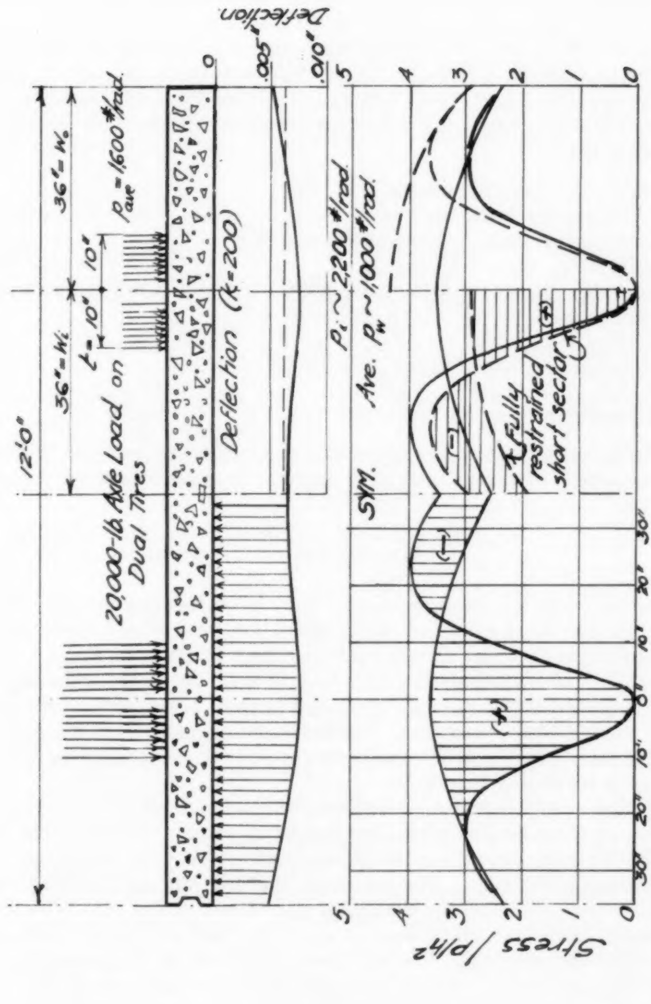


Fig. 13 Transverse sector deflections, distributed sector loads, and transverse sector stresses for normal dual-tire single-axle lane loading.

are inter-related. The equalized stress diagram is shown in the left half of Fig. 13; in terms of distributed transverse average sector load, the transverse apex stress approximates 3.6 p/h^2.

No test data are known for this, the most common highway traffic loading. Extending the computations for a 9-7-9-in. slab with 8 in. average thickness and 7 1/2-in. apex thickness, with 5,000,000-psi. modulus of elasticity, on a subgrade with 200-pci. modulus, the following stress derivations apply for a 20,000-lb. axle load:

Longitudinal soil reaction sector, Fig. 10	85 in.;
Average tire sector load,	1,600 lb./radian;
Distributed sector loads, equations (3) and (4):	
longitudinally, $(n_i = 2.5)$, p_i,	2,200 lb./radian
transversely, average, $(n_w = 1.0)$, p_w,	1,000 lb./radian
Longitudinal stress for tire load sector of .07 i,	
$4.8\ p_i/h^2 = 4.8 \cdot 2{,}200\ /\ 7.5^2 =$	188 psi.;
Transverse stress, adjusted per Fig. 13,	
$3.6\ p_w/h^2 = 3.6 \cdot 1{,}000\ /\ 7.5^2 =$	64 psi..
Deflection under wheel, equation (7),	.0076 in.

As indicated by the above computations the transverse stresses become relatively insignificant for normal axle loadings on single-lane pavement slabs.

Edge Axle Loading

This loading condition away from slab ends is defined by an axle with its outer wheel tangent to the edge of the lane and its inner wheel centered about 7 ft. from the edge. A study of this load condition is given in Fig. 14 for a 20,000-lb. axle load with dual-tire imprints 12 in. long, 20 in. wide and the inside tire centered 80 in. in on a 12-ft. slab with 9-7-9-in. cross section on a subgrade with 300-pci. modulus. The dimensions conform to the pavement of Road Test One-MD, for which load tests and stresses have been reported by the Highway Research Board.[8]

Edge loading conditions apply for the outside wheel, interior loading with relatively short transverse sectors for the inner wheel. Soil reaction sectors and distributed sector loads may be determined initially for the single wheel loads as outlined previously. The resulting transverse single-wheel deflection diagrams and wheel-stress diagrams are shown in Fig. 14. The deflections for individual wheel loads may be superimposed giving the composite deflection diagram indicated. The soil pressure distribution is thereby changed to approximately constant pressure from the inner wheel for an interior central sector, and to a distribution with decreasing pressure from the apex to the constant-pressure value for the outside sector perpendicular to the edge at the wheel; for the sector on the far side of the inner wheel the soil pressure distribution decreasing to zero would be as initially assumed. As long as the deflections at the wheels are unchanged, the loads distributed to the longitudinal sectors remain unchanged.

The composite deflection line shown satisfies vertical force equilibrium, but it does not satisfy sector stress equilibrium; the negative stress in the outside sector must be equaled by a negative stress at the end (the zero shear plane) of the central sector. As a necessary deflection condition the slab under the inner wheel tilts toward the loaded edge, resulting in decreased

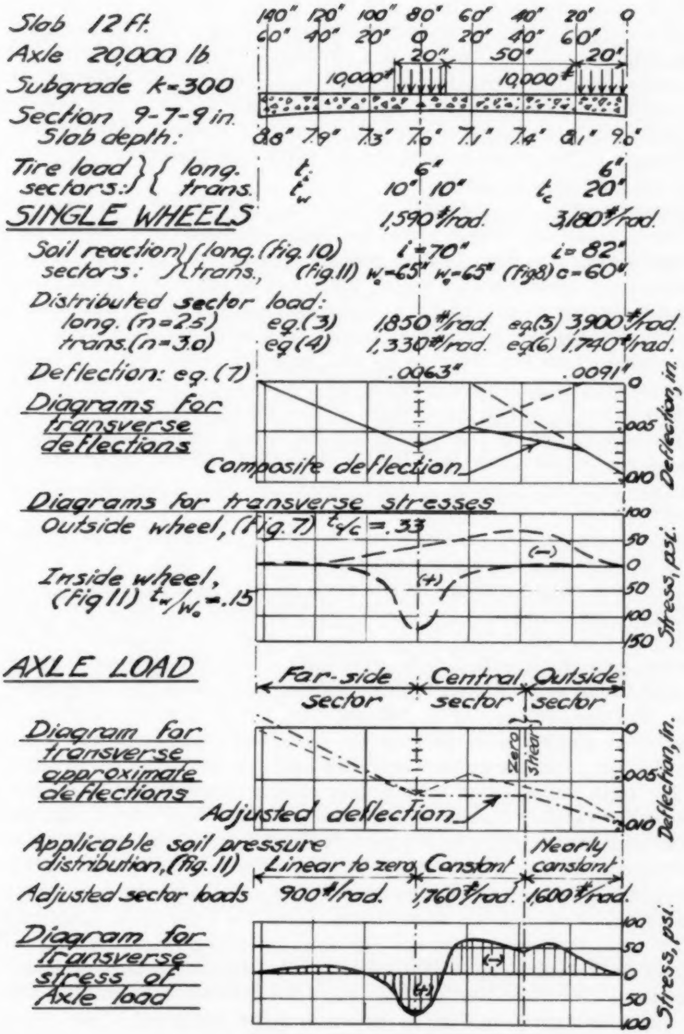


Fig. 14 Axle edge loading on 12-ft. highway slab, showing computation of distributed sector loads, transverse sector deflections and stresses; adjustment from single-wheel to axle loading.

load on the far-side sector, with an equivalent increase in load on the central sector, and some increase in deflections under the axle approximately to the adjusted transverse deflections for axle load shown in Fig. 14, as a constant deflection for the central sector. The zero shear plane between the wheels is displaced toward the edge; both sectors under the axle may be analyzed for conditions approximating constant soil pressure as shown in Fig. 11, with the central sector load and restraint adjusted so as to obtain a negative stress at the end equal to the end stress in the short outside sector and a positive apex stress under the inner wheel equal to the positive stress of the far-side sector at the apex. The transverse stresses satisfying these conditions are shown in the axle-stress diagram of Fig. 14.

As derived in Fig. 14, the deflections under both wheels are practically unchanged from those for single wheel loadings, the loads distributed on the longitudinal sectors in Fig. 14 then remain unchanged. Longitudinal stresses are estimated in accord with Fig. 10, for t/i of 6/70 for the inside wheel and 6/82 for the outside wheel, to 4.5 p/h^2 or 170 psi. for 7-in. depth and to 4.6 p/h^2 or 230 psi. for the 9-in. edge stress. The maximum transverse stresses, taken from Fig. 14, are 80-psi. positive stress bending under the inner wheel, with negative stresses of 55 psi. in the outside sector and 65 psi. in the central sector. The transverse stress for the inner single wheel alone (Fig. 14) would be 125 psi. Adjusted for Poisson's ratio of .15 the stresses under the inner wheel would be: for the axle load 186 psi. longitudinally and 108 psi. transversely, and for a single wheel 193 psi. longitudinally and 154 psi. transversely.

Edge stresses and deflections were observed for single-axle trucks with the wheel 6 in. or more from the edge of the slab in Road Test One-MD;(8) by extrapolation edge stresses and deflections for the wheel tangent with the edge 20% greater than those for the wheel 6 in. from the edge were prorated, (Fig. 134 and Fig. 135 of Ref. 8) for slabs on granular subgrade. Observed edge stress changes for 20,000-lb. axle load at creep speed were 180 psi. for night warped slab and 130 psi. for day warped slab, with corresponding deflections .010 and .005 in., (Fig. 143 and Fig. 144 of Ref. 8); prorated to axle with one wheel tangent with the edge the observed stress changes would be 215 and 155 psi., and the deflections .012 and .006 in. (The observed stress change for night warped slab is probably smaller than actual load stress due to decrease in warping stress incident to slab curvature under load in direction from fully restrained toward unrestrained temperature warping.) The edge stress and deflection according to Fig. 14 are 230 psi. and .009 in.

Inner wheel stresses were observed for an axle load with one wheel tangent with the center joint and one wheel 60 in. from the free edge, longitudinal stress 185 psi., transverse stress 125 psi., including .15 Poisson's ratio. (Fig. 77 of Ref. 8 for longitudinal stress; transverse strains obtained in correspondence.) The observed stresses are not directly comparable with the loading case illustrated in Fig. 14 because of the influence of the center joint; the joint probably provided no flexural restraint, but served to unload part of the joint edge load onto the adjacent slab. The computed inner-wheel stresses for the Fig. 14 loadings were 186 and 193 psi. longitudinally and 108 and 154 psi. transversely for the axle load and for a single wheel load, respectively. If the center joint effect is assumed equivalent to one half wheel load at the edge the inner-wheel stresses of Fig. 14 for axle load and single-wheel load might be averaged to 190 psi. longitudinal and 131 psi. transverse stress, which would compare with the observed stresses of 185 psi. longitudinally, and 125 psi. transversely.

CLOSURE

The Sector Analysis applications to common highway loadings in above examples illustrate its procedural simplicity. Computed stresses and deflections are in satisfactory agreement with experimental observations in spite of the rough first-approximation deflection lines used for stress derivation. The coordination between deflection lines and stress computations in Sector Analysis has specific applications to variable slab conditions.

The investigational procedures of Sector Analysis are not too time consuming, considering the value and importance of the pavement structure. More important is the possibility to predict conditions for actual tire loads and limited slab dimensions with fair accuracy. The stresses in above examples could not have been deduced easily by purely mathematical procedures.

Soil reaction sector radii, bending sector lengths, and distributed sector loads might be estimated with better accuracy than done in this presentation. For extended use it is desirable to have available stress diagrams and soil reactions for intermediate soil pressure distributions between those for linear decrease to zero and constant pressure.

Tests for which literature information is available have been directed primarily toward coordination between the Westergaard analysis and observed stresses. Observations which would be of special value for refinement of Sector Analysis are mostly not available. The beneficial influence of increasing size tire imprint deserve further experimental and analytical consideration.

Temperature variations and concrete volume changes, as well as loads, induce stresses in concrete slabs of normal pavement dimensions. Critical stresses are the result of combinations of these influences. A representative analysis of load and stress distributions and elastic load deflections in principal directions at different initial curvatures is essential for study and understanding of interrelations between these different influences. Sector Analysis appears to be usable for this purpose.

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DIVISION ACTIVITIES
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEWS

January, 1957

HIGHWAY DIVISION EXECUTIVE COMMITTEE

1956 ---- 1957

Professor Harmer E. Davis (Zone IV) Institute of Transportation & Traffic Engineering University of California Berkeley 4, California	Chairman	1957
Bertram D. Tallamy (Zone I) New York State Thruway Authority P. O. Box 189 Albany 1, New York	Vice Chairman	1958
William A. McWilliams (Zone II) 43 E. Division Street Dover, Delaware	Member	1959
A. N. Carter (Zone III) Lindsey, Carter & Associates, Inc. Tonka Terrace Shopping Center Excelsior, Minnesota	Member	1959
J. Paul Buckley Automotive Safety Foundation 200 Ring Building 1200 18th Street, N.W. Washington 6, D. C.	Member Secretary	----
R. Robinson Rowe 2701 Third Avenue Sacramento 18, California	Board Contact Member	1956-1957

Appointment expires in October of year listed opposite name.

Lowell E. Gregg Assistant Director of Research State Department of Highways 132 Graham Avenue Lexington, Kentucky	Board Contact Member	ASCE Research Committee

Note: No. 1957-2 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol., 83, HW 1, January, 1957.

HIGHWAY DIVISION
January 15, 1957

The Highway Division has become increasingly active during the past year. As of September 1956, our membership was 3850, an increase of 1350 over the previous year.

The Division is reviewing its program of cooperation with other societies and organizations. Plans are under way for exploration of the subject with the American Association of State Highway Officials.

Members of the Executive Committee of the Highway Division represented the Society at the President's Regional Safety Conferences in Atlantic City (May 1 and 2), Chicago (May 23 and 24) and San Francisco (May 31, June 1).

Harold J. McKeever resigned in April because of pressure of other work and J. P. Buckley was appointed as Secretary.

Executive Committee meetings were held in Washington in January and May and in Pittsburgh in October.

FEBRUARY MEETING
Jackson, Mississippi
February 18-22, 1957

Professor Ben T. Collier, State Aid Engineer, Mississippi State Highway Department, is making arrangements for the four Highway Division sessions at this meeting. The schedule of speakers and subjects for these sessions follows:

Tuesday, February 19, morning session

Joint Session with Surveying and Mapping Division on Photogrammetric Mapping

Presiding: Prof. Milton O. Schmidt, Member, Executive Committee, Surveying and Mapping Division

(program prepared by the Surveying and Mapping Division)

Tuesday, February 19, afternoon session

Current Problems Relating to Control of Access

Presiding: J. Paul Buckley, Member, Executive Committee, Highway Division

Interstate Highway Standards

Conrad H. Lang, M. ASCE, Chief Engineer
New York State Thruway Authority
Albany, New York

Special Operation Problems on Controlled Access Facilities

Charles M. Noble, M. ASCE, Chief Engineer
New Jersey Turnpike Authority
New Brunswick, New Jersey

Location Requirements to Obtain Full Benefit from Freeways

B. P. McWhorter, M. ASCE, Division Engineer, Division 3
U. S. Bureau of Public Roads
Atlanta, Georgia

Benefits of Freeways

Terry J. Owens, M. ASCE, Urban Highway Engineer
Automotive Safety Foundation
Washington, D. C.

Wednesday, February 20, afternoon session

Management and Manpower Problems in the Expanded Highway Program

Presiding: Ben T. Collier, Chairman, Program Committee, Highway Division

The City's Plate in the Expanded Highway Program

Glen C. Richards, Commissioner of Public Works
City of Detroit, Michigan

Alfred Berarducci, Expressway Engineer
City of Detroit, Michigan

Importance of Good County Management

Lee B. Brandon, M. ASCE, County Engineer
Lauderdale County, Meridian, Mississippi

The Use of Technicians in Highway Engineering

Scott H. Lathrop, A.M. ASCE, California Division of Highways
Sacramento, California

Francis J. Farias, Associate Personnel Analyst,
California State Personnel Board

Manpower Problems in the Highway Program

Carl E. Fritts, M. ASCE, Vice President in Charge of Engineering
Automotive Safety Foundation
Washington, D. C.

Thursday, February 21, morning session

Symposium: Highway Planning and Finance

Presiding: Harmer E. Davis, Chairman, Executive Committee, Highway Division

Discussion of Certain Phases of Highway Planning in Missouri and Mississippi by:

Samuel M. Rudder, M. ASCE, Engineer of Highway Planning
Missouri State Highway Department
Jefferson City, Missouri—"Highway Planning as used in the States"

I. W. Brown, State Manager, Traffic Planning
Mississippi State Highway Department
Jackson, Mississippi—"Methods of Field Location Surveys and Estimate in Mississippi"

Highway Planning—Past, Present and Future

E. H. Holmes, Deputy Commissioner and John T. Lynch,
A. M. ASCE, Chief, Planning Surveys Section
U. S. Bureau of Public Roads
Washington, D. C.

BURGGRAF AWARDED RESEARCH PRIZE

At the May 7 meeting of the Division's Executive Committee, Fred Burggraf was unanimously endorsed as a nominee for a Society Research Award. The November issue of "Civil Engineering" carried the following item:

"The 1956 Research Prices were awarded to

1. Fred Burggraf, M. ASCE, director of the Highway Research Board, Washington, D. C., in recognition of his outstanding contributions to knowledge through the administration of research in highway engineering and construction materials."

NEW COMMITTEE POLICY

At the Annual Meeting in Pittsburgh in October, the Division's Executive Committee considered and adopted a new policy in regard to Division committee memberships. All members of administrative and technical committees will be appointed on a three year basis with new committee members starting off on staggered one, two and three year terms to set the plan in motion. This policy was adopted in recognition of the fact that committee memberships have been a great burden on some Division members, many of whom had served on committees since the founding of the Division. It was considered that a rotation system would minimize these burdens and, in addition, would permit more Division members to participate in committee activities.

There follow reports on the activities and lists of members of each of the Division's committees.

ADMINISTRATIVE COMMITTEES

Committee on Highway Division Publications

Leo J. Ritter (Chairman), A. W. Johnson, R. M. Schwegler, Francis E. Twiss, F. N. Wray, J. A. Leadabrand, J. W. Spencer, K. W. Crowley.

The recent death of Mr. M. Alfred Kaehrle is noted with regret. New members on the committee are Messrs. Leadabrand and Spencer.

The committee has reviewed or has under review a total of 22 papers. Seven of these have been published; five others have been recommended for publication.

The committee held a meeting at Knoxville, Tennessee, in June, 1956. Plans were discussed for getting more and better papers on highway subjects. The possibility of publishing a list of current literature in the Journal is under discussion.

Two issues of the Newsletter were published in 1956, in the January and May "Highway Journals."

A news release was prepared to take the place of the fall Newsletter. This release concerned the Highway Division program at the Pittsburgh meeting and was circulated to magazines and organizations to arouse interest in the sessions.

The "Highway Division Committee Member Handbook" is now in the process of publication.

Committee on Cooperation with Local Sections

Sylvester E. Ridge (Chairman), W. F. Babcock, W. A. Bugge, J. L. Cheatham, Jr., J. N. Clary, Ellis Danner, John R. Dietz, George L. Epps, Curtis J. Hooper, Charles C. Morris, John O. Morton, Edward J. Nunan, S. M. Rudder.

As now organized, there are vacancies in representation from Zones 7 and 9.

Chairman Ridge Reports in part as follows:

"Last year was probably one of the most important, insofar as highway engineering is concerned, that we have ever witnessed. The Congress authorized and financed the construction of the National System of Interstate and Defense highways and I feel that the effort put forth by this committee in having the local sections express their opinion on this legislation and in making those views known to Congress was, to some measure, responsible for the successful passage of the legislation. I am sure also that our work in assisting the President's Special Committee on the Highway Program in their effort to have each local section hold a special meeting on the subject was also of substantial value and was appreciated by the National officers.

"The passage of the legislation authorizing and financing this program is, however, only the beginning. The big job, the construction of this most important highway system is still to be accomplished and the local sections of the American Society of Civil Engineers can be of great assistance in making certain that the system constructed is adequate in every respect and that, after it is constructed, it is maintained and operated so that traffic can use it in an efficient and safe manner.

"In order that the local sections can be effective in dealing with highway matters, the highway division feels that each should have an active technical committee on highway matters. Several do not. It has been suggested, therefore, that the Committee on Cooperation with Local Sections should endeavor to see that each local section has such a committee and that it should assist the local sections, wherever such action is feasible, in establishing such committees. We should, therefore, make this our primary activity this coming year."

Committee on Session Programs

Membership is made up of the chairman and secretary of the Highway Division Executive Committee and chairmen of highway sessions of national meetings. This has included the following two committees:

For 1956: Randle B. Alexander (Dallas, February, 1956), Prof. E. A. Whitehurst (Knoxville, June, 1956), James W. McKnight (Pittsburgh, October, 1956).

For 1957: Ben T. Collier (Jackson, Miss., Feb. 1957), Edward J. Nunan (Buffalo, June, 1957), Edward S. Olcott (New York, October, 1957).

The committee held a meeting at Knoxville in June, 1956, and in Pittsburgh in October, and plans were outlined for future meetings. It is felt

this committee has performed excellent work in setting up highway sessions at the meetings of the Society.

TECHNICAL COMMITTEES

Committee on Developments in Highway Engineering and Construction

A. N. Carter (Chairman), Bonner Coffman, Wilson T. Ballard, Joseph Barnett, W. M. Carey, Jr., Raymond J. Hodge, L. O. Stewart, Eugene M. Johnson, W. T. Pryor, James J. Mennis, Robert J. Ratner.

The committee has been active in supplying information on articles and speeches relating to the highway engineering and construction field to Civil Engineering, Transactions and Proceedings.

The committee has now been enlarged and it is planned that individual members will submit papers on special fields of activity in which they have an interest.

Committee on Geometrics of Highway Design

Conrad H. Lang (Chairman), Ralph L. Fisher, Donald W. Loutzenheiser, Jacob C. Young, M. J. Madigan, Wilson T. Ballard.

The committee held its first meeting in October, 1955, and set up an outline of proposed activities.

Because of his serious illness, Wilson T. Ballard has resigned as chairman. Conrad H. Lang has been appointed to take his place and a new member, M. J. Madigan, has been added to the committee.

Chairman Lang reports in part as follows on the meetings of this committee held during the National Convention in Pittsburgh in October.

"The Committee met during the mornings of October 16 and 17, 1956, with C. H. Lang, R. L. Fisher, D. W. Loutzenheiser and M. J. Madigan present. Mr. Young was unable to attend. Also present was E. F. Passarelli of the staff of Madigan-Hyland whose services were made available by Mr. Madigan. Visitors at the first meeting were: E. H. Karrer, H. E. Davis and J. P. Buckley of the Highway Division Executive Committee.

"The immediate objective of the Committee is the review, analysis and interpretation of the Geometric Design Standards for the National System of Interstate and Defense Highways. These have been adopted by the American Association of State Highway Officials and the U. S. Bureau of Public Roads in July 1956 and have been augmented by policy and procedure memorandum of the Bureau of Public Roads dated August 10, 1956.

"It is the consensus of the Committee that the design standards and the policy memorandum referred to above are adequate to provide a broad base for the design and construction of the interstate system. Inevitably, however, questions can be expected to be raised concerning the interpretation of various phraseology in these documents, some of which were discussed during the Committee meetings, such as the following:

1. Are frontage roads constructed as an adjunct to the expressway eligible for Federal participation?
2. What is to be done with regard to the necessity for service areas for food and gasoline?

3. What will govern the selection of route locations? Are present routes to be closely paralled or are departures to be made therefrom?
4. In addition to the above points which are most important, the Committee also discussed a host of minor features of design, such as the manner and method of providing access, signs, highway striping, number of lanes, fencing, maintenance, etc. The discussions indicated the desirability of bringing some of these points to the attention of the people who would be most concerned with them in order that they can be recognized in the initial designs.

"As a first order of business it is the belief of the Committee that we should issue at once, preferably in Civil Engineering magazine, a statement to the effect that the Committee and the Society heartily endorse the standards as adopted, and with that statement publish the design standards together with the policy memorandum by the Bureau of Public Roads for the edification and enlightenment of all of our members. The purpose of this is to acquaint as many engineers as possible with the provisions of these documents so that first-hand knowledge will be available to those who can help the most in furthering the coming program by thoroughly understanding what must be done and the obstacles to be overcome.

"Our second objective is to discuss some of the detailed problems which will have to be surmounted in order to advance with the work of design and construction. In this connection, the Committee has been asked to present a paper at the Jackson, Mississippi meeting of the Society in February. It is expected that Mr. Passarelli and others of Mr. Madigan's staff will assist in preparing the necessary material for presentation at that meeting. If these details can then be published in a suitable organ and disseminated among those most concerned, we feel that a great many mistakes can be avoided in progressing designs to conclusion.

"In general, we believe that the biggest task will be to impress everyone with the desirability of maintaining more than just the minimum standards. It will be our consistent endeavor to do this, to maintain liaison with the American Association of State Highway Officials and to attempt to resolve differences of opinion with regard to design features. In order to have adequate representation on the Committee from various sections of the country, it is requested that at least one and possibly two additional members be appointed to the Committee to represent the plains and mountainous areas of the mid and far West."

It may be noted that this committee's recommendation of endorsement of the Geometric Design Standards for the National System of Interstate and Defense Highways was subsequently carried out.

Committee on Highway Engineering Manpower

Carl E. Fritts (Chairman), Dwight H. Bray, Harmer E. Davis, Harold G. Sours, Robley Winfrey.

A guidebook or checklist for use by public officials in appraising and analyzing their engineering manpower problem is in the process of preparation. A first draft of Report No. 1, "Salaries and Incentives" is under review by members of the committee. Material for this report was obtained by a

questionnaire to all state highway departments and several consulting engineers concerning the so-called fringe benefits of engineering employment. Response to this questionnaire was almost 100 percent. Work on this checklist will continue.

Chairman Fritts reports in part as follows on the meeting of this committee at Pittsburgh in October.

"Status of the proposed guidebook series, or checklist dealing with the highway engineering manpower problem was discussed in considerable detail. The series is to be a compilation of activities under way and necessary projects to improve existing conditions and to overcome the present deficiency in available engineering manpower.

"The guidebook is visualized as a series of individual and independent reports, each dealing with a separate phase of the problem. A first draft of Report One on the subject of salaries and incentives has been prepared. Other reports will cover the subjects of management policies, training and recruitment, technological developments, manpower utilization.

"Professor Davis suggested the urgent need for a revised classification of professional help for highway engineers. His idea is the creation of a professional corps of technicians for work above the so-called subprofessional levels but not requiring full time attention or execution by professional engineers. He outlined progress being made in this direction in California. Basic training for such technicians in the various specialized fields might require the equivalent of two years at the college level. There would be need to define areas in which such technicians could be used advantageously. Adequate performance and training standards would have to be developed and established.

"Need for a brochure describing career opportunities in highway engineering for distribution at secondary school level was discussed. Preparation of such a brochure will be undertaken in the immediate future. It is hoped to have the first draft ready for the meeting at Jackson, Mississippi in February, 1957."

Committee on Highway Planning and Finance

Ralph A. Moyer (Chairman), John Clarkeson, Thomas J. Fratar, Lowell E. Gregg, Roy E. Jorgensen, John T. Lynch.

The committee has been active in setting up a program of work. Three meetings have been held, in New York in October, 1955, in Washington in January and June, 1956. They have held discussions along two general lines: to decide on a study program in which members of the committee might participate or the entire committee might engage, and to decide on papers or topics which might result in papers for presentation at an ASCE meeting. Their plans now include a symposium on highway planning at the Jackson, Mississippi meeting in February, 1957.

Committee on Significance of Tests for Highway Materials

Taylor D. Lewis (Chairman), Robert F. Baker, Fred J. Benson, Ray Bollen, George A. Rahn, Tilton E. Shelburne, Ralph E. Simpson, J. F. Barbee.

Due to the pressure of other duties, Lowell Gregg resigned from membership during the past year.

The committee has submitted the reports to the Division Publications Committee for review and possible printing.

During a meeting of the committee, in Washington, January 18, 1956, continuance of the committee was discussed. This led to concurrence of committee members that there were still two areas to cover: that of less used but standard tests, and seldom used and controversial tests. They also recommended that the committee be augmented.

Committee on Traffic Engineering

Wilbur S. Smith (Chairman), H. A. Mike Flanakin, Burton W. Marsh, Donald M. McNeil, George M. Webb.

Chairman Smith reports in part as follows:

"A meeting of the Committee on Traffic Engineering of the Highway Division of the American Society of Civil Engineers was held at the Mark Hopkins Hotel, San Francisco, California, September 25, 1956. All members of the committee were in attendance.

"Mr. Smith opened the meeting by explaining that the Traffic Engineering Committee had been in existence for more than a year, having been created by the officers of the Society for the purpose of developing interest and activity within the proper spheres of the Society in traffic engineering. It was pointed out that while the committee had not been especially active, that there had been considerable correspondence between the Chairman and some members and that there seemed to be general agreement that principal contributions can be made initially through the sponsorship of technical papers at meetings of the Society. A desire was indicated to activate the committee and to move forward as rapidly as possible with a sound and continuing program.

"Mr. Flanakin reviewed the work of traffic engineers in relation to other engineering and indicated the feeling that the committee has an opportunity to make a substantial contribution not only to the traffic engineering profession, but to highway engineering and civil engineering groups as a whole. The cementing of better working relationships and the development of a proper understanding of abilities and objectives within all phases of highway work should be constantly considered by the Committee.

"There was general agreement that early attention must be given to the development of a full understanding of the proper place of traffic engineering within the A.S.C.E. The Committee wants to make it known to the offices and Executive Committee, to other technical committees, and to the membership, that traffic engineers are very anxious to play an important role in the Society and that, insofar as proper, the committee will assist.

"It was the desire of these present that the committee be charged with the responsibility of developing papers and technical articles for A.S.C.E. publications. It was emphasized that the papers, insofar as possible, should be given before general sessions of the various meetings of the Society. By having the presentation at general sessions, it will be possible to reach a higher percentage of the membership and to accelerate the goals of the traffic engineering membership.

"There was a feeling that the vigorous approach that has been evidenced by traffic engineers as a young professional group might appear out of keeping at times with the more conservative approaches of the Society. If this

is true, then the traffic engineering group should be careful in 'pacing' its activities so that they will be properly understood and accepted.

"To expedite the development of technical papers, a substantial part of the meeting was devoted to discussion of subjects and potential speakers.

"The chairman was instructed to contact suggested speakers to determine whether or not the suggested papers can be prepared and presented. First, however, the chairman was to ascertain from the officials of the Highway Division whether or not space can be scheduled for the papers on the programs of forthcoming meetings of the Society."

COMMITTEES BEING ORGANIZED

Proposed Committee on Highway Maintenance and Operations

A special sub-committee has developed a purpose for this committee, as follows:

Committee purpose: to develop, and encourage the development of, new methods and procedures for the adequate and economic maintenance and the safe and efficient operation of highways and appurtenant facilities; to sponsor activities designed to increase the over-all knowledge of new maintenance methods and equipment; to investigate and report on specific problems in the field of highway maintenance and operation; to act as a focal point within the Society for all activities relating to highway maintenance and operation; and to cooperate with other committees both within and without the Society to effect the above objectives.

This "Purpose" has been approved by the Society's Committee on Division Activities.

As yet, no permanent members have been appointed to this committee.

Committee on Urban Transportation

Norman Kennedy (Chairman), Nathan Cherniack, Harold J. McKeever, John A. Logan, William R. B. Froehlich, Terry J. Owens.

Committee purpose: to aid in advancing knowledge relating to the administration, economics, planning, design, construction and operation (including use) of the internal transport facilities required for the functioning of metropolitan and urbanized communities. The Committee will cooperate with other committees inside and outside the Society in supporting research and in assembling and disseminating information pertinent to urban transportation problems.

This newly formed committee has not yet had its initial meeting.

Newsletter Editor:

George H. Leland
Edwards, Kelcey and Beck
3 William Street
Neward 2, New Jersey

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1113 is identified as 1113 (HY6) which indicates that the paper is contained in issue 6 of the Journal of the Hydraulics Division.

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JANUARY: 861(SM1), 862(SM1), 863(EM1), 864(SM1), 865(SM1), 866(SM1), 867(SM1), 868(HW1), 869(ST1), 870(EM1), 871(HW1), 872(HW1), 873(HW1), 874(HW1), 875(HW1), 876(EM1)[c], 877 (HW1)[c], 878(ST1)[c].

FEBRUARY: 879(CP1), 880(HY1), 881(HY1)[c], 882(HY1), 883(HY1), 884(IR1), 885(SA1), 886(CP1), 887(SA1), 888(SA1), 889(SA1), 890(SA1), 891(SA1), 892(SA1), 893(CP1), 894(CP1), 895(PO1) 896(PO1), 897(PO1), 898(PO1), 899(PO1), 900(PO1), 901(PO1), 902(AT1)[c], 903(IR1)[c], 904 (PO1)[c], 905(SA1)[c].

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APRIL: 925(WW2), 926(WW2), 927(WW2), 928(SA2), 929(SA2), 930(SA2), 931(SA2), 932(SA2)[c], 933(SM2), 934(SM2), 935(WW2), 936(WW2), 937(WW2), 938(WW2), 939(WW2), 940(SM2), 941 (SM2), 942(SM2)[c], 943(EM2), 944(EM2), 945(EM2), 946(EM2)[c], 947(PO2), 948(PO2), 949(PO2), 950(PO2), 951(PO2), 952(PO2)[c], 953(HY2), 954(HY2), 955(HY2)[c], 956(HY2), 957(HY2), 958 (SA2), 959(PO2), 960(PO2).

MAY: 961(IR2), 962(IR2), 963(CP2), 964(CP2), 965(WW3), 966(WW3), 967(WW3), 968(WW3), 969 (WW3), 970(ST3), 971(ST3), 972(ST3)[c], 973(ST3), 974(ST3), 975(WW3), 976(WW3), 977(IR2), 978(AT2), 979(AT2), 980(AT2), 981(IR2), 982(IR2)[c], 983(HW2), 984(HW2), 985(HW2)[c], 986(ST3), 987(AT2), 988(CP2), 989(AT2).

JUNE: 990(PO3), 991(PO3), 992(PO3), 993(PO3), 994(PO3), 995(PO3), 996(PO3), 997(PO3), 998 (SA3), 999(SA3), 1000(SA3), 1001(SA3), 1002(SA3), 1003(SA3)[c], 1004(HY3), 1005(HY3), 1006 (HY3), 1007(HY3), 1008 (HY3), 1009 (HY3), 1010 (HY3)[c], 1011 (PO3)[c], 1012 (SA3), 1013 (SA3), 1014(SA3), 1015(HY3), 1016(SA3), 1017(PO3), 1018(PO3).

JULY: 1019(ST4), 1020(ST4), 1021(ST4), 1022(ST4), 1023(ST4), 1024(ST4)[c], 1025(SM3), 1026 (SM3), 1027(SM3), 1028(SM3)[c], 1029(EM3), 1030(EM3), 1031(EM3), 1032(EM3), 1033(EM3)[c].

AUGUST: 1034(HY4), 1035(HY4), 1036(HY4), 1037(HY4), 1038(HY4), 1039(HY4), 1040(HY4), 1041(HY4)[c], 1042(PO4), 1043(PO4), 1044(PO4), 1045(PO4), 1046(PO4)[c], 1047(SA4), 1048 (SA4)[c], 1049(SA4), 1050(SA4), 1051(SA4), 1052(HY4), 1053(SA4).

SEPTEMBER: 1054(ST5), 1055(ST5), 1056(ST5), 1057(ST5), 1058(ST5), 1059(WW4), 1060(WW4), 1061(WW4), 1062(WW4), 1063(WW4), 1064(SU2), 1065(SU2), 1066(SU2)[c], 1067(ST5)[c], 1068 (WW4)[c], 1069(WW4).

OCTOBER: 1070(EM4), 1071(EM4), 1072(EM4), 1073(EM4), 1074(HW3), 1075(HW3), 1076(HW3), 1077(HY5), 1078(SA5), 1079(SM4), 1080(SM4), 1081(SM4), 1082(HY5), 1083(SA5), 1084(SA5), 1085(SA5), 1086(PO5), 1087(SA5), 1088(SA5), 1089(SA5), 1090(HW3), 1091(EM4)[c], 1092 (HY5)[c], 1093(HW3)[c], 1094(PO5)[c], 1095(SM4)[c].

NOVEMBER: 1096(ST6), 1097(ST6), 1098(ST6), 1099(ST6), 1100(ST6), 1101(ST6), 1102(IR3), 1103 (IR3), 1104(IR3), 1105(IR3), 1106(ST6), 1107(ST6), 1108(ST6), 1109(AT3), 1110(AT3)[c], 1111(IR3)[c], 1112(ST6)[c].

DECEMBER: 1113(HY6), 1114(HY6), 1115(SA6), 1116(SA6), 1117(SU3), 1118(SU3), 1119(WW5), 1120(WW5), 1121(WW5), 1122(WW5), 1123(WW5), 1124(WW5)[c], 1125(BD1)[c], 1126(SA6), 1127 (SA6), 1128(WW5), 1129(SA6)[c], 1130(PO6)[c], 1131(HY6)[c], 1132(PO6), 1133(PO6), 1134(PO6), 1135(BD1).

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c. Discussion of several papers, grouped by Divisions.

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